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Journal of Environmental &Earth Sciences

Volume 3 • Issue 2 • October 2021 ISSN 2661-3190(Online)

Volume 3 Issue 2 • October 2021 • ISSN 2661-3190 (Online)

Journal of Environmental & Earth Sciences

Editor-in-Chief

Prof. Shuanggen Jin

BILINGUAL PUBLISHING CO.
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Volume 3 | Issue 2 | October 2021 | Page1-86
Journal of Environmental & Earth Sciences

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REVIEW

Environmental Problem Analysis and Policy Recommendations on Pacific Northwest Salmon

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ARTICLE INFO

Article history
Received: 24 May 2021
Accepted: 18 June 2021
Published Online: 10 August 2021

Keywords:
Environmental problems
Pacific northwest salmon
Policy proposal
Political analysis

ABSTRACT

Environmental issues are becoming hot topics nowadays. As the steps of industrialization and urbanization expand, the conflict between economic development and environmental protection appears to intensify and catch people's eyes more frequently, from the disappearing Amazon rainforest to the pollution of Mississippi River. Over the past few months, the news of one species, salmon, dying out in the northwestern part of the United States drew our team's attention. In this paper, I would like to present my research on Pacific Northwest salmon from the perspectives of problem statement, policy proposal, and political analysis.

1. Introduction

In the Pacific Northwest, salmon were threatened with extinction. An article called *Northwest's Salmon Population May Be Running Out of Time*, written by Fazio [1] briefly stated this emergent issue and explained how several factors caused the large reduction of salmon, which included toxic pollution, artificial barriers and unusual warmth. It was the growing human population and rapid development that made it hard for salmon to adapt to the changing environment quickly enough. Under this circumstance, their survival was at stake. After only four or five generations, this species was estimated to die out.

Neglecting the negative externalities for the society, a great number of transportation construction and energy infrastructures were established along the shoreline. The man-made pro-development facilities made a harmful influence on salmon's habitat and the related pollutants also exacerbated salmon's living circumstances. As can be seen, the absence of policy intervention has led to the disastrous condition of salmon population. Therefore, an effective policy is required. Under this circumstance, policy intervention is necessary for the salmon aggravating problem.

A promising solution is being proposed by Congressman Mike Simpson [2]. He aims to restore the Lower Snake River and salmons through the "removal of four federal dams, funding for the Yakima Basin Integrated Plan, incentives to remove select fish-blocking dams in the Columbia Basin, and increasing tourism and recreation opportunities" [3]. From my perspective, it is an appropri-

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 https://doi.org/10.30564/jees.v3i2.3284

ate response since most detrimental human behaviors are originated from the existing dams. The biggest advantage of the policy is that directly dealing with the source of the issue, together with additional stimulus to the economy are very likely to contribute to a success. Ideally speaking, the joined efforts can boost the recovery of salmons at a fast speed. However, the disadvantage of the policy is the violation of some factories' interests in that area, because of which the policy implementation may encounter the opposition from these groups. Comparing this trade-off to the huge benefits of salmon restoration, the weaknesses fall behind. A similar successful dam removal policy existed elsewhere, for example, the removal of Edwards Dam in 1999, letting the species there rebound and recover.

2. Discussion on Problem Mechanisms and Potential Resolutions

The policy that I believe would be most beneficial to achieve the goal of saving Pacific Northwest salmon is the removal of specific dams and the simultaneous addition of water treatment facilities to the water flow. The primary appeal of this policy is the reestablishment of the river's natural flow, which in turn will restore the natural environmental functions and habitats of the surrounding ecosystem that originally supported a larger salmon population. Although dams benefit clean energy production in short-term consideration, the costs of their maintenance and environmental interruption severely outweigh the positive results [4]. Dams are detrimental to the microclimates of surrounding areas through major water cycle changes, such as mass evaporation causing temperature fluctuation disruption.

Dams do not solely disrupt the natural temperature fluctuation, however. The unnatural patterns of water movement cause a sensation known as "hungry water"- where the flowing water is high energy with little sediment. In turn, this disrupts the chemical composition of the river that gives guiding signals to migrating species, such as birds and other fish going through their biological processes [5]. The physical barrier goes further to prevent these natural occurrences, as the physical barrier restricts access to the traditional safe spawning and rearing habitats. Through this series of obstacles, the natural behavioral patterns of native species, specifically salmon, have been disrupted in the interest of human development.

The implementation of water treatment facilities following the natural flow of water will dive even further into supporting the regression of nature back to its original function, providing the necessary aeration and supplement balance to support a major influx of salmon in these bodies of water. According to Clean-Flo [6], as the water cycle changes, the nutrient content of the water will be regulated by certain types of water filters that will reduce the impact of this drastic change on the local bodies of water.

The policy change with the greatest potential for salmon population recovery with the lowest risk factors would be the removal of the four Lower Snake River dams. Although these dams generate electricity, there is a great cost to the natural ecosystems that eliminate the dams as a sustainable energy source if any concern is to be given to the environment. Possible risks associated with this major change create a large fear factor, as the water cycle changes could potentially affect surrounding communities long-term, raise costs of energy production, and alter the availability of aquatic resources for the local consumers.

When comparing the alternatives, I would like to discuss the options available for energy production for the communities that rely heavily on the energy produced by the water-driven generators existing on these dams. As they exist, the costs of the water energy generators are severely imbalanced by the negative costs and effects of their existence. When considering other options, there are multiple alternative clean energy sources, such as windmills or solar power, that have a lower risk factor and less detrimental environmental effects.

Another discussed topic in this policy development was the management of water runoff. The sheer magnitude of a serious project like this is a risk in itself, as the possibility of detrimental effects on the water's already elevated level of pollution is a major concern as the runoff has the potential to collect and sit there. This would be a devastating result to not only the salmon population, but the surrounding communities, ecosystems, and habitats of coexisting species would all suffer the mass destruction of their existence as it is.

Because of this, there is the potential for conflicts in this policy's implementation. These risks include the potential effects on the environment from the deconstruction of these dams, such as changing fish and bird migration patterns and compromising the established function of the natural water cycle of the surrounding environment, which could pose flood risks for the surrounding areas. The removal of these dams will also affect the abilities of these communities, especially considering their use as sources of clean electricity generation. Local areas are rightfully concerned with the possibility of tax increases resulting from this loss of mass energy production. Because of these negative effects that removing the dams could bring to local communities, there is a significant rate of local opposition to this policy. Despite the serious risks and concerns associated with this proposed policy, the potential benefits that the policy could bring outweigh

  https://doi.org/10.30564/jees.v3i2.3284

the negatives in tenfold.

Although this particular policy regarding the removal of these exact dams has not been played out and attempted before, there is research on similar situations that suggests that this would be a positive option to regenerate the salmon population of the Pacific Northwest. The results of these similar attempts combine to support the idea that this policy correlates with the greatest potential recovery of the salmon slump.

The closest relative example to this policy is the Puget Sound Salmon Recovery projects. The findings of these efforts suggest that, while dams benefit salmon populations in short-term results by providing a sort of rest place in their lifetime and an option for a life-supporting safe habitat, there are methods of supporting the salmon population with long-term sustainability in mind. Through removing these dams, salmon populations will at first lose this safe point, but will eventually revert back to their natural habitats and behavioral patterns as the river returns to its native flow [7]. As the current man-made habitat features are removed, the original natural salmon habitats will slowly restructure to the areas that supported their larger population in the first place.

Another consideration to make for the repopulation of salmon in the Pacific Northwest is the function of hatcheries, which take fish eggs and assure their safety in their development. Although these hatcheries are beneficial to the salmon population by creating the ideal artificial environment for salmon in order to breed a larger population at a faster rate, they are also depleting the natural resources necessary to support the local natural ecosystem. However, if necessary, hatcheries are an option that may be considered should the need arise for a major population increase as the immediate result of the dam removal by change in habitat. These hatcheries assure that with the fluctuation in salmon population after the dam removal, there will not be an entire extinction of salmon native to the Pacific Northwest.

Puget Sound salmon recovery efforts also gave insight into what may be a primary concern in this policy's implementation. Throughout the series of efforts, shoreline salmon habitat destruction has been a consistent battle that has yet to reach a sustainable and logical solution. This alone is a large contributor to the depletion of Pacific Northwest salmon population fluctuation, but the removal of dams that add pressure to the shoreline has the potential to allow recovery of these natural safe ecosystems.

Throughout similar policy implementation documented by Puget Sound Partnership [8], the idea of compromise between federal, tribal, state, and local organizations has become an important formative structure in the success of the attempted goal, in this case, the regeneration of the Pacific Northwest salmon population. Although political conflicts influence the belief systems, participation, and goals of each division, these groups, should the policy regarding the dam removal be approved, will be forced to come to a compromise for the betterment of the native environment that supports a large variety of important systems stemming from the original salmon population's survival.

Some of the compromises regarding these divisions include the potential monetary costs of the project itself, the effects on the developed ecosystem that an influx of salmon population growth will have, and the supporting and opposing interest groups or communities behind this policy. These criteria are important to consider and decide before the implementation of this proposed policy, as their conflicts if left unaddressed could potentially ensure the failure of the salmon population recovery, leading to a further detrimental effect on the ecosystems and local communities.

The potential costs lying behind this policy lie primarily in labor, as the dam removal, hatchery development, energy redirection, and changes in irrigation are all full remodeling projects that will require materials, time, effort, and skills. A series of professionals in a wide variety of fields will be required to do a full evaluation, build or remove structures properly, support the local communities and ecosystems in their survival and comfort, and determine the best route of action to benefit the salmon population without compromising the surrounding life or land. The costs of a major change in energy production, as the dam removal also removes water-driven energy generation in a multitude of areas, is also something that will need thoughtful consideration.

Energy production is already a very controversial subject among political and environmental interest groups, and according to Born [9], the removal of this significant source of clean energy will drive the interest of certain groups, whether positively or negatively. For example, energy moguls and urban expansion supporters would be expected to be opposed to the policy, as the removal of these energy generators would be a step backwards from their goals. Alongside them, the local population may potentially advocate against this policy in fear of its effects on the comfort and economic situations of their communities and surrounding areas. In contrast, environmental advocacy groups may be expected to support this policy, as it is designed to fully benefit the natural ecosystem structure of the Pacific Northwest and will restore the habitats that originally supported salmon population with minimal human intervention.

In the change of the dam removal, however, there is a plethora of environmental change factors to consider in the policy development. As dams change the water cycle by producing a larger standstill body of water, leading to a higher rate of evaporation [9], the removal of such would potentially reduce the rain level by a significant amount. Flooding of local communities, especially as the water cycle is in the process of reregulating itself, is also a considerable factor. Natural predators and prey of the surrounding ecosystem will also experience a major change, which could potentially risk other resources and put other habitats at a similar situational disadvantage in the future.

3. Policy and Political Analysis on Resolution Proposal

Though the removal of the four Lower Snake River Dams would restore the salmon population of the region, the main concern of passing this policy is convincing other interest groups that the benefits of this move outweigh the potential problems that could arise from doing so. Obviously, the power provided by the four dams would have to be replaced, which is an expensive process. On top of that, the dams provide a number of other benefits, such as allowing cheap transport of goods via barges, which is a major blow to Idaho's agricultural farmers.

The political aspect of the policy implementation requires not only demonstrating that the policy would work, but that the solution can work with minimal impact to potential affected parties, such as farmers who will need alternatives to transport of goods, local communities, who need the power provided by the dams, and taxpayers, who need justification on why such a plan is important for preserving the local wildlife of Idaho.

The Lower Snake River Dams are federal dams, which means that legislation would have to reach the Federal Government to get the necessary approval for breaching the dams. However, past attempts to receive permission to breach have failed, as several agencies, including the Army Corps of Engineers, the Bureau of Reclamation, and, most importantly, the Bonneville Power Administration, have deemed the ordeal too costly and too taxing on the Northwest power grid.

These parties are relatively neutral when it comes to local wildlife restoration, but their position is heavily affected by technical feasibility of the proposal. If the breaching of the dams were to destroy local irrigation systems, or the power generated by the dams couldn't be replaced. Then they would be less likely to support our legislation and would advise Congress to vote against it. The main focus of our political approach should consider their concerns in our strategy, as they've been a major roadblock to similar legislation in the past.

On top of getting approval from these essential administrations, the policy needs to pass at the congressional level. Alternative solutions to previous legislation have been put in place, such as spilling water over the dams during the spring. However, these alternatives won't create an impactful level of restoration, and will continue to promote reliance on the dams which have caused severe damage to local ecosystems. To reach this level of legislation, we will need to utilize a key actor within Congress.

The most essential key actor to utilize for promoting our policy is United States Congressman Mike Simpson. He represents Idaho's 2nd district and shows great interest in salmon restoration in the region. The Congressman has attended hundreds of meetings on the subject and attempted to bring legislation to the House of Representatives, which failed due to the aforementioned reasons. Congressman Simpson is our best chance at proposing legislation to Congress, which is nearly essential if we have any hope of making our proposal a reality.

At the current moment, similar policies have been extremely popular among environmental groups as well as communities who rely on fishing and tourism for their local economies. Losing the salmon population could potentially destroy tourism and fishing within the region. Another major supporter of the policy is the Shoshone Bannock Tribes, who've seen the drastic decline of salmon in the rivers for decades as a result of the dams. "The fish aren't coming back, nothing is working here", says Nathan Small, a leadership member of the Shoshone Bannock [10]. The destruction of the salmon population would tarnish the fishing grounds they've been using throughout their history. It's important to utilize the support of these groups because they represent the communities around these rivers and ecosystems. If their concerns are made apparent and they're encouraged to call their congressperson, more and more support can be gained in Congress and more legislatures would be on board.

On the other side, our largest potential opponents include the Bonneville Power Administration, who need a comprehensive plan to either match or exceed the power output of the dams, and local farmers, who need confirmation that the plan won't damage their irrigation systems or completely hinder current transportation routes. It's absolutely necessary that our political approach includes farmers, as their support is essential to prove that our plan is feasible.

Farmers must be supported by this legislation as they are potentially the most impactful when it comes to public support. Their grievances can be linked to two major concerns, transportation of crops and irrigation. Farmers in

  https://doi.org/10.30564/jees.v3i2.3284

the region largely rely on barges as a cheap and effective way to transport their crops. These barges rely on the waterways created by the dams in order to traverse the river safely, so breaching the dams could make these waterways difficult to traverse. In recent years, however, barge transport has mostly been on the decline. “Over the past 20 years even grain volume has declined by more than 40 percent”[11]. This means that as barge transport phases out over time, potential externalities involving crop transportation can be avoided.

Another concern from farmers is irrigation, as current irrigation systems rely on the waterways altered by the dams. However, a majority of farmland is inland from the river, and systems that actually utilize the river can be extended via pipes. This may be one of the trickier portions of the proposal since reconstruction of these systems may be required, but the support of local farmers is essential enough to warrant it.

The Bonneville Power Administration manages the electric power market on the Columbia River, which connects to Snake River. As a result, they are the main party that needs convincing in terms of power production. At the current moment, they don’t support breaching the dams because, if the region were to replace the energy produced by the lower Snake dams, it would most likely be with a fossil fuel, natural gas” [12]. They will require a comprehensive plan that utilizes clean energy.

Alternative energy such as wind and solar isn’t something new in the Lower Snake River Valley. Wind farms already have a considerable presence in the region under Puget Sound Energy, the operation created 149 turbines that produces “enough annual electricity to power 70,000 homes, while also contributing jobs and commerce to the local economy” [13]. If it is possible to cooperate with the BPA to establish a deadline for more wind farms in the region to match the output of the dams, then they may be convinced to support the recommended proposal.

The nature of policy requires that the political approach should be one of reassurance and assessing who is affected by what. The key actor Mike Simpson must be utilized to present the legislation to Congress and take advantage of his knowledge on the subject, as well as identify where his legislation has failed in the past. The legislation must address the concerns of the potential oppositions. Therefore, the approach should be oriented to address concerns of those parties and organizing them to take the position of saving Pacific Northwest salmon. Last but not least, gaining the support of the local people is vital. There are parties in favor of the legislation already. However, including the needs of skeptics to the resolution proposal, mainly farmers, are necessary as well. If their needs are addressed and their stance on the issue swings in the favor of environmentally friendly, the new supporters will contact their congressperson and create even more supports in the House and the Senate.

4. Conclusions

This issue needed to be solved because it was closely related to the local people’s lives. Salmon was the vital species for the environment, economy and culture there. Specifically, more than 138 species cannot live without salmon in those food chains, according to Cederholm et al. [14]. As an essential link in the pacific northwest region, salmon’s absence could lead to a devastating collapse in that ecological system. A worsening environment was obviously not a piece of good news to the residents. In addition, Hagenbuch [15] indicated that the loss of salmon risked around 16,000 unemployment in the commercial and recreational fishing industry. Less salmon would result in fish stock shortage and tourism decline, and these two markets’ economies would be damaged consequently. Moreover, salmon played an important role in Native American’s culture there, acting as a cultural heritage for indigenous tribes. Galbreath et al. [16] studied the negative impacts of salmon slump to the well-being of tribal peoples, in which salmon fostered their religion and cultural belief. For thousands of years, salmon shaped the lives of the people who have lived here since time immemorial. Moreover, Crozier et al. [17] warned that salmon would become extinct by 2060 and this issue desperately needed immediate actions. There was a market failure at play, due to the tragedy of the commons. Specifically, the ecological habitat of salmon is a common pool, where people there neglected the well-being of society in the pursuit of personal gain. The dams were built out of economic purposes, however at the cost of negative externality towards the environment. Considering all the elements above, the endangered situation of salmon should be taken into consideration at least by the local government.

The decisions and behaviors of governmental actors and interest groups to this issue, namely Pacific Northwest legislators, governors, native American tribes, residents and factory stakeholders are important factors that contribute considerable efforts into the problem, especially during the legitimation and implementation process of the effective policy. An example of potential venue shopping related to this case would be Washington State Recreation and Conservation Office and Idaho Department of Environmental Quality. Both of them are state agencies in Pacific Northwest region of the United States and they are responsible for environmental protection and conservation. To achieve the final goal of saving Pacific Northwest salmon, more research and proposals are needed to form useful alliance. I expect the coalition of government environment departments and local residents will be formed because the salmon distinction issue is going to affect the regional economy as well as the life quality of the people. With this alliance structured, the policy can confront less obstacles and impediments.

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https://doi.org/10.30564/jees.v3i2.3284

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Journal of Environmental & Earth Sciences
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ARTICLE

Geochemical Trends in Weathering Profiles and Their Underlying Precambrian Basement Rocks in Akure, Southwestern Nigeria

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ARTICLE INFO

Article history
Received: 2 June 2021
Accepted: 21 July 2021
Published Online: 10 August 2021

Keywords:
Akure
Nigeria
Geochemical trends
In-situ weathering profile
Kaolinitic

ABSTRACT

Akure area in southwestern Nigeria falls within the basement complex underlain by migmatite, quartzite granite and charnockite. Geochemical features of these crystalline rocks and their overlying in-situ weathering profiles are investigated and reported. Analytical result from ICP-MS facility at the University of Malaya reveals average SiO_2 content in quartzite (91.1%), granite (73.8%), migmatite (67.4%) and charnockite (58.6%) categorize the rocks as siliceous. SiO_2 contents in the weathering profiles above these rocks are 61.9%, 60.2%, 52.2% and 54.6% respectively. Alumina contents in the weathering profiles overlying quartzite (23.8%), granite (19.9%), migmatite (26.3%) and charnockite (24.3%) are substantially higher than the precursor rocks. In the same order, average alkali (Na_2O+K_2O) contents in the profiles are 3.38%, 3.42%, 3.48% and 2.68%. Chemical features of the profiles reflect that there exists some correlation between the chemistry of crystalline basement and their in-situ weathering profiles. The residual soils contain low plastic clays with kaolinitic characteristics and compare well with other clays reported from other parts of Nigeria basement complex.

1. Introduction

Akure area in southwestern Nigeria falls within the tropical rain forest zone and the climatic conditions favour both physical and chemical weathering. The alternating wet and dry seasons coupled with high humidity equally allow rapid disintegration of its rocks. Vast expanse of land located towards eastern side of Akure is formed from accumulated residues of weathering in form of rock debris deposited after transporting medium localized them in the vicinity and low-lying areas adjoining prominent residual hills. The plains extend southwards into sedimentary sequences of essentially alluvium and coastal sands interbedded with lignite shale which covered substantial parts of riverine areas of Ondo State. About two-third of the land mass of Ondo State is covered by crystalline rocks and this occur towards the north. The general landscape of Akure area which consists of gently rolling hills of average heights has an undulating topographic outlook. Akure and its environs are underlain by basement complex rocks. A dominant part of these rocks is weathered in-situ to form profiles with varying thicknesses and physical properties over these residual hills. Chemical weathering which ultimately transforms these residues becomes so pronounced that they differ from their precursor basement rocks. In the current study, these weathering profiles are investigated for geochemical trends that may be related to their parent rocks.

The crystalline rocks in Akure area forms part of the Precambrian basement complex of southwestern Nigeria

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 https://doi.org/10.30564/jees.v3i2.3308

which on a regional continental scale is an extension of the Pan-African province that extends into over twelve countries in Africa. Within this province, the Nigeria domain contains crystalline and sedimentary rocks which share the landmass almost equally. The sedimentary rocks which are Cretaceous to Recent in age occupy the major basins and overly the basement complex with recognizable unconformities. The crystalline rocks are categorized into three petrological groups. These are migmatite gneiss quartzite complex, schist belts and granite (Figure 1). Previously, several authors e.g. [1-8] have presented the petrological affiliations, mineralogical features, petrochemical characteristics and structural geology of these ancient basement in sections. While the petrogenetic synopsis and geochronology of the rock units have been investigated e.g. [9-13]. More frequently reported among these rocks is the Schist belts e.g.[14-17] which host several tangible economic mineralization in gold [18,19] Banded Iron Formation (BIF) [20-23], marble, [24] and several clay deposits scattered within the basement complex of southwestern Nigeria e.g. [25-27]. However, Akure section of the basement complex of southwestern Nigeria is underlain by migmatite-gneiss, quartzite, granitoids (undifferentiated coarse-grained granite (OGu), medium-grained granite (OGe), porphyritic biotite and biotite hornblende granite (OGp), fine-grained granite (OGf) and charnockitic meta-intrusive (Ch) (Geological Survey of Nigeria, [31]) (Figure 2). This geological map was adopted for the study and it guided immensely during geological sampling. About 70% of the study area is covered by migmatite which extends from north-western to north-eastern direction. However, the north central part of Akure is occupied by granite-charnockite units. Migmatite-gneiss had geological contacts with charnockite towards the west and coarse-porphyritic granite towards east and medium-grained granite toward northeast. The granite-chanockite association continues along a linear strip into Ekiti and Kwara State in the north. Field examination reveals dominance of quartzo-feldspartic aggregates which points the rocks as acidic. However, the opaque constituents are more obvious in charnockitic unit, granite only has specks of these minerals scattered among the interlocking aggregates with dominance of biotite and iron oxide which form the main mafic minerals. The relationship between textural characteristics, mineralogical composition, degree of weathering and strength of rocks has been established in several investigations [28,29].

2. Materials and Methods

Field geology entails sampling of the chemically decayed in-situ rocks overlying bedrocks in the study area. Samples are collected at different locations and at different depths within each profile with the help of a hand trowel and are labelled accordingly. Samples of the soil profile are subjected to laboratory procedure first by drying for two weeks at room temperature; they are kneaded and subsequently pulverized. Rocks and weathering profiles powders are packaged in air-tight plastic containers and analysed by the ICP-MS facility at the Department of Chemistry, University of Malaya, Malaysia. Four samples each were collected from profile above the quartzite, charnockite, granite and migmatite. Another set of four samples each of the basement complex rocks represented by quartzite, charnockite, granite and migmatite were subjected to geochemical analysis. The total number of samples was limited to thirty-two (sixteen for weathering profiles and sixteen for fresh basement rocks). For analytical procedures, collected weathering profile and underlying basement rock samples were dried at 60°C, crushed, pulverized and sieved to -80 mesh. About 0.2 g samples aliquot was weighed into a graphite crucible and mixed with 1.5 g of $LiBO_2/LiB_4O_7$. The samples were heated in a muffle furnace which has its temperature set at 980°C for 30mins. The cooled beads were dissolved in 100 mL of 5 % HNO_3. The aliquot of the solution was poured into a propylene test tube. Calibration standards and verification standards are included in the sample sequence. Sample solutions are injected into an ICP-MS (Perkin- Elmer Elan 9000) and major elements composition was determined.

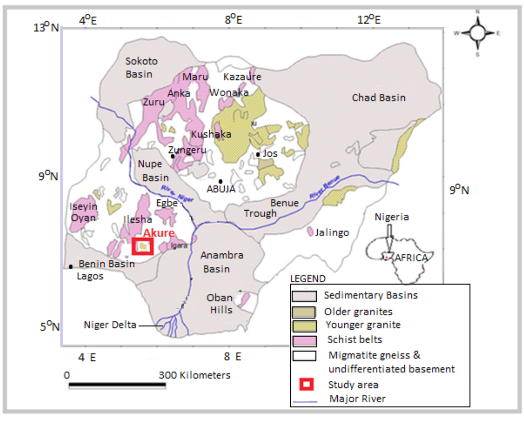

Figure 1. Geological map of Nigeria showing study area (after [30])

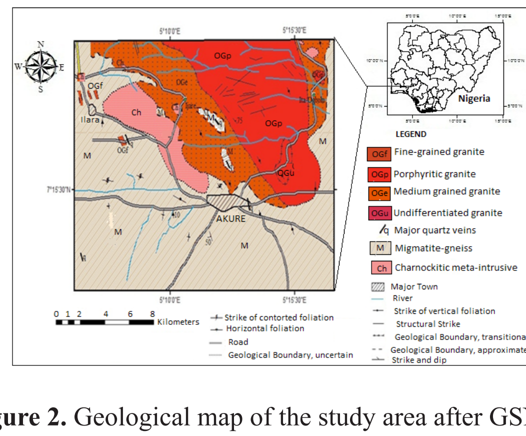

Figure 2. Geological map of the study area after GSN [31].

https://doi.org/10.30564/jees.v3i2.3308

3. Results and Discussion

3.1 Description of the Profiles

The profiles are associated with the rocks exhibit variation in colour, texture, and weathering intensities. The thicknesses, grain sizes and other physiographic features also vary significantly from one location to another (Figure 3). Colour varies from white to yellowish brown in profiles above quartzite around Ijapo Estate (Figure 3a), while the colour ranges from grey to light brown along Akure-Owo Expressway (Figure 3b). Profiles above porphyritic granite (Figure 3c) appear finer while those above migmatite (Figure 3d) are coarser. Textural variation in the profiles might have probably resulted from or at least influenced by differences in textures of the parent rocks. This equally may indicate the different lithologies have different susceptibilities to weathering. The degree of weathering is partly dictated by rock's mineralogy. Rocks with coarse grains are more susceptible to weathering than when the same rock has fine grains [30].

Figure 3. Colour and textural variation in profiles above crystalline basement rocks in Akure area, (a) a low-lying quartzite exposed after the thin veneer of reddish-brown soil overlying it was excavated as filling material and part of the outcrop locally sourced for building stone in Ijapo Estate area of Akure, (b) a thick grey to yellowish-brown profile overlying charnockite exposed by gully erosion along Akure-Owo Expressway, (c) yellowish-white residual soil formed from *in-situ* weathering of medium grained granite in the study area, (d) a reddish-brown profile above a chemically decayed in-situ migmatite in the study area .

3.2 Geochemical Trends

Analytical results of weathering profiles (Table 1) and the crystalline rocks underlying them (Table 2) are presented. Average analytical results in the study were compared to similar rocks in different parts of Nigeria as reference samples (P, Q, R, S and T) (Table 3). Analytical results (Table 1) show that the weathering profile is siliceous, SiO_2 contents range between 61.4-62.3% in the profile above quartzite. The profile overlying charnockite, granite and migmatite has values ranging between 54.1-54.9%, 59.4-60.8% and 51.9-52.3% respectively. Geochemical features of the weathering profiles are significantly different from the underlying basement rocks. Average silica content of weathering profile above quartzite (61.9%) is higher than the one above granite (60.2%), charnockite (54.6%) and migmatite (52.2%). However, these average silica values are significantly lower that the values for their respective (quartzite, 91.1%; granite, 73.8%; charnockite, 58.6%; and migmatite, 67.4%) precursor rocks. Average alumina values in profile above migmatite (26.3%) is higher than charnockite (24.3%), quartzite (23.8%), and granite (19.9%). The discrepancies between average values of this oxide in the weathered profile and basement rocks which are respectively 13.1%, 15.2%, 1.8% and 1.8% may have arisen due to mineralogical variation and the degree of weathering as Al_2O_3 values are higher in the weathered products. During the breakdown of rocks, feldspar and micaceous components ultimately produce aluminosilicate mineral residues that accumulate as clay minerals. There appear to be an insignificant difference between average Fe_2O_3 contents in quartzite (1.7%) and its weathered profile (1.94%), this may have links with monomineralic nature of the quartzite being made of metamorphosed quartz grains which does not change significantly during weathering activities. However, like the basement rock of chanockitic composition which has the highest average Fe_2O_3 value (6.4%), the weathered profile above it equally records the highest value of 3.15%. The higher average value recorded in charnockite may have resulted from ferromagnesian minerals like orthopyroxene, biotite, and iron oxide. The marginally lower average values in granite (6.2%) and migmatite (4.3%) may be due to lower percentage of these mineral aggregates in them. The slightly lower average values of this oxide in the weathering profile must have been attributed to chemical decomposition of ferromagnesian mineral because of their instability at near surface environments. Both basement rocks in Akure area and the weathering profiles above them contain appreciable amount of Na_2O and K_2O. The average value of alkali (Na_2O+K_2O) appears to follow a coherent pattern with migmatite recording the highest value (5.22%) while weathered profile above migmatite equally record a maximum value (3.48%). The average sum of alkalis in charnockite (3.46%) and granite (3.25%) which yielded minimally lower values produces a corresponding lower value 2.68% in profile above charnockite and 3.42% in profile above granite. Similar geochemical trends between the basement rocks and their weathering profiles (Figure

Table 1. Analytical result of weathering profiles above the basement rocks

Rock	Profile A (above Quartzite)				Profile B (above Charnockite)				Profile C (above Granite)				Profile D (above Migmatite)			
S/No	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Oxides																
SiO_2	62.3	61.8	61.4	62.1	54.1	54.4	55.1	54.9	59.4	60.8	60.2	60.5	52.3	51.9	52.3	52.1
Al_2O_3	23.5	23.7	23.7	24.1	24.5	24.5	23.9	24.2	20.1	19.4	20.1	20.3	26.3	26.1	26.4	26.4
Fe_2O_3	2.16	1.83	1.85	1.90	3.12	3.08	3.08	3.3	1.55	1.48	1.57	1.60	2.43	2.45	2.61	2.37
MgO	0.07	0.08	0.08	0.08	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.04	0.05	0.05	0.05	0.05
CaO	0.52	0.58	0.58	0.54	0.43	0.41	0.47	0.42	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
MnO	0.03	0.01	0.02	0.02	0.01	0.01	0.01	0.01	-nd-	-nd-	-nd-	-nd-	0.01	0.01	0.01	0.01
Na_2O	1.89	1.79	1.83	1.82	1.68	1.62	1.59	1.63	2.11	2.08	2.05	2.01	1.95	1.97	1.93	1.89
K_2O	1.69	1.56	1.43	1.50	0.93	1.04	1.01	1.25	1.32	1.37	1.40	1.35	1.56	1.51	1.62	1.48
TiO_2	1.14	1.11	1.20	1.2	6.84	6.53	6.81	6.42	1.06	1.06	1.03	1.05	0.06	0.05	0.05	0.05
P_2O_5	0.02	0.02	0.02	0.02	-nd-	-nd-	-nd-	-nd-	-nd-	-nd-	-nd-	-nd-	0.01	0.01	0.01	0.01
LOI	6.68	7.52	6.79	6.72	8.14	8.36	7.99	7.83	14.4	13.7	13.57	13.1	15.3	15.8	14.9	15.6
Total	100	100	100	100	99,8	100	100	99.9	99.9	99.9	100	99,9	100	99.8	99.9	99.9

Note: -nd- (not determined).

Table 2. Chemical features of basement complex rocks in the study area

Rock	Quartzite				Charnockite				Granite				Migmatite			
S/No	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Oxides																
SiO_2	89.9	91.2	91.7	91.5	58.7	58.9	58.3	58.6	73.9	73.8	74.0	73.5	67.4	67.4	67.2	67.5
Al_2O_3	1.82	1.68	1.71	1.95	15.20	15.2	15.2	15.3	9.5	9.1	9.8	9.4	12.6	14.1	12.8	12.9
Fe_2O_3	1.75	1.68	1.71	1.65	6.51	6.35	6.49	6.37	6.7	5.3	6.7	5.9	4.11	4.62	4.37	4.25
MgO	0.14	0.15	0.11	0.17	2.96	3.04	3.10	2.96	1.85	1.91	1.83	1.88	1.89	1.75	1.69	1.74
CaO	0.11	0.17	0.14	0.15	4.37	4.28	4.34	4.31	2.11	2.08	2.16	2.17	2.51	2.37	2.14	1.64
MnO	0.01	0.01	0.01	0.01	0.15	0.14	0.18	0.15	0.03	0.03	0.03	0.01	0.01	0.01	0.01	0.01
Na_2O	0.04	0.04	0.05	0.03	0.59	0.61	0.60	0.60	2.54	2.37	2.41	1.29	1.75	1.83	1.72	1.66
K_2O	0.06	0.08	0.04	0.06	2.91	2.87	2.83	2.85	1.16	1.04	1.07	1.11	3.61	3.57	3.49	3.25
TiO_2	0.03	0.03	0.04	0.03	0.81	0.79	0.80	0.74	0.1	2.8	1.0	2.8	0.69	0.75	0.48	0.62
P_2O_5	0.02	0.02	0.04	0.01	0.01	0.01	0.01	0.01	-nd-	-nd-	-nd-	-nd-	-nd-	-nd-	-nd-	-nd-
LOI	6.12	4.94	4.45	4.44	7.79	7.81	8.15	8.11	2.14	1.58	2.0	1.94	5.4	3.6	6.1	6.43
Total	100	100	100	100	100	100	100	100	100	100	100	100	99.9	100	100	100

Note: -nd- (not detected).

Table 3. Comparison of average chemical composition of the profile with similar rocks

Oxides	Profile A Quartzite	Profile B Charnockite	Profile C Granite	Profile D Migmatite	(P)	(Q)	(R)	(S)	(T)
SiO_2	61.9	54.6	60.2	52.2	56.9	47.9	38.67	59.97	64.45
Al_2O_3	23.8	24.3	19.9	26.3	27.2	33.07	9.45	24.66	20.28
Fe_2O_3	1.94	3.15	1.55	2.47	1.90	3.15	2.7	3.32	0.63
MgO	0.08	0.05	0.05	0.05	-	0.19	8.5	0.27	0.12
CaO	0.55	0.43	0.03	0.03	0.63	0.58	15.84	0.46	0.28
MnO	0.02	0.01	-nd-	0.01	trace	trace	-	0.01	0.01
Na_2O	1.83	1.63	2.06	1.94	1.59	1.19	2.76	1.78	0.18
K_2O	1.55	1.06	1.36	1.54	1.72	1.17	2.76	0.48	0.42
TiO_2	1.16	6.65	1.05	0.05	1.12	1.25	-	20.2	0.84
P_2O_5	0.02	-nd-	-nd-	0.01	0.03	0.03	-	-	-
LOI	6.9	8.08	13.69	15.4	6.56	8.00	-	16.14	-

Note: -nd- (not detected); trace (below detection limits)

P: Greyish clay [32]; Q: Reddish brown clay [32]; R: Industrial clays and rocks [33]; S: Kaoline deposits, Ubulu-Uku, Awo-Omama and Buan, Southern Nigeria; [34]; T: Iyuku clay [35].

 https://doi.org/10.30564/jees.v3i2.3308

4) indicate coherent relationship exists between them. The correlation of values may imply copious evidence that the composition of weathered products of these rocks significantly depend on the parent rock. Analytical result (Table 1 and Table 2) reveals that the loss of ignition (LOI) values is high. However, LOI values are higher in the weathering profiles when compared to their crystalline rock equivalent. The difference may be due to higher porosity or ability of the weathering residues to absorb water into their crystal structures which is ultimately given off during decomposition of the soil during analysis as loss on ignition. Except for higher SiO_2 values, the chemical composition of Akure weathering profile resembles that of clay and lateritic soils. Even though the physico-mechanical parameters of these overlying soil profiles are not evaluated in this study; however, field examination reveals they are of low plasticity and can barely be moulded into balls when water was added implying, they tend towards kaolinitic clay. Previous research reveals that clays in the basement complex areas of Nigeria could exhibit variable geochemical features or differ markedly in their industrial application. Average silica content of weathering profile above quartzite (61.9%) in Akure is marginally lower than Iyuku clay [35] (Table 3). However, silica content of weathering profile above granite (60.2%) in Akure area is comparable to Kaoline deposits reported by [34] from Ubulu-Uku, Awo-Omama and Buan areas of Southern Nigeria. Average alumina content of reddish-brown clay (33.07%) [32] is significantly higher than all the investigated soil profiles in Akure. However, the average content of this oxide in profile above charnockite (24.3%) is comparable to kaoline deposits (24.66%) from southern Nigeria [34]. This average is equally higher than clay (9.45%) evaluated by [33] and Iyuku clay [35]. Average Fe_2O_3 content in profile above charnockite (3.15%) in Akure area is comparable to the reddish-brown clay [32] while the average iron content in profile above quartzite in the study area (1.94%) is comparable to grey clay (1.90%) [32]. All the weathering profiles evaluated from the study contain CaO contents that are grossly lower than (15.84%) recorded for industrial clays [33]. Average TiO_2 contents of weathering profiles in the study area are grossly lower than Kaoline deposits from Ubulu-Uku, Awo-Omama and Buan, area of southern Nigeria [34]. This research indicates that weathering residues across many domains of Nigeria basement are compositionally variable.

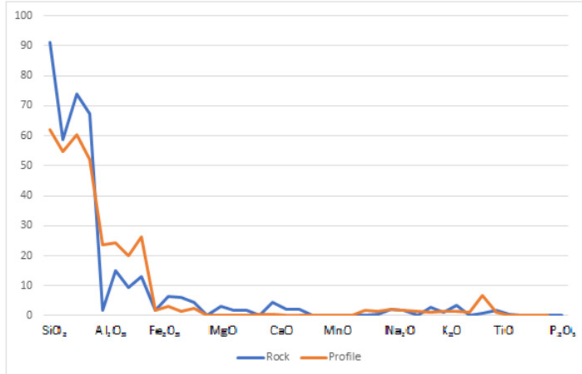

Figure 4. Correlation of chemical composition of the basement rocks and the weathering profiles.

4. Conclusions

From the study, the following conclusions are made. The weathering profiles are formed in-situ and vary in colour, texture, and thickness. The composition is siliceous and there exist some correlations between the chemistries of weathering profile and their underlying crystalline basement rocks. The geochemical features of the profiles portray high alumina and alkali contents but with slight variations that are related to the parent rock chemistry. Field investigation shows the weathering profiles have characteristic features comparable to kaolinitic and low plastic clays and are like other industrial clay deposits in southern Nigeria.

Acknowledgements

The authors wish to acknowledge with thanks a Research Fellow in person of Dr. Seidu Akun Abdallah of the Department of Chemistry, University of Malaya for facilitating the geochemical analysis. Students who assisted on logistics during fieldwork are equally appreciated.

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ARTICLE

Urbanisation Footprints and the Distribution of Air Quality in Nairobi City, Kenya

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ARTICLE INFO

Article history
Received: 25 May 2021
Accepted: 4 August 2021
Published Online: 31 August 2021

Keywords:
Urbanisation
Urban morphology
Air quality
Development density
Land use
Biomass index

ABSTRACT

Various postulations on the relationship between urban morphology and air quality are qualitative. This fails to establish the strength of the contributions of each morphological parameter in the spatial distribution of the air quality. It is this gap in knowledge that this study sought to fill by modelling the correlation existing between the urban morphological variables of development density, land uses, biomass index and air quality values of Nairobi city. While 30 development zones of the city constituted the target population, IKONOS satellite imagery of the city for the year 2015 was utilised in establishing the development densities, land uses and biomass index. The parameters were transformed into numerical surrogates ranging from 1 to 10 with lower values accorded to zones with low biomass index, the highest development density, noxious land uses, high gaseous concentrations and *vice-versa.* Pearson's correlation coefficients (r), coefficients of determination (R), *t*-tests and the Analysis of Variance (F-tests) with levels of significance being 95% were used to determine the strengths, significances and consistencies of the established relationships. The study established that development density is the most significant morphological variable influencing the distribution of air quality. This is followed by biomass index and to a weaker extent, land uses.

1. Introduction

Nairobi has witnessed high urbanisation rate as the city's population grew from 270,000 to 4,397,073 between the years 1963 and 2019, respectively. This represents approximately 4.7% annual growth rate compared to 3.5% per annum for major African cities [1,2]. This has been occasioned by modest national economic growth, high rural-urban migration and natural population increase rates as well as favourable physiographical base of the city, which apart from providing excellent sources of building materials has also lowered the construction costs [3]. Over the years, the increasing urban population has been accommodated through urban sprawl, with built-up areas expanding into the natural vegetation, causing ecological disruptions. Since urbanization is a major factor in global warming and climate modification, cities with high urbanisation rates such as Nairobi are associated with the same. The establishment that global warming and climate change is exacerbated by urbanisation and greenhouse gas (GHG) emissions has heightened studies on the correlations between urbanisation footprints of development densities, land uses, biomass index and the urban environmental quality parameters such as the urban heat islands, air quality, climate change and global warming. The urban morphological attributes notably;

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DOI: https://doi.org/10.30564/jees.v3i2.3289

development densities, building configurations, street orientations and widths, man-made structures and green belts attenuates wind velocity within the canyons and the urban canopy layers, consequently affecting the dispersal and concentration of the air pollutants.

Land uses, building configurations and the distribution of development densities within an urban area influences the transportation mode used in the city as well as the city's energy consumption and GHG emissions. This is because proximity of homes and concentration of services coupled with provision of efficient public transportation accentuated by compact urban development encourages walking, cycling and use of mass transportation instead of private motor vehicles. This consequently leads to decline in fossil fuel consumption per capita. However, this is complicated by the fact that urban centres are industrial hubs and GHG emissions coming from industries outstrip those from the transportation sector. Overall, empirical evidence shows that cities are responsible for 75% of global energy consumption and 80% of GHG emissions. Compact developments induce usage of less energy for heating. For example, households in the United States of America living in single-family detached housing consume 35% more energy for heating and 21% more energy for cooling as compared to households living in other forms of housing due to urban heat island effect [4].

As corroborated by energy usage differentials in four urban spatial structures notably; mono-centric, polycentric, composite (multiple-nucleic) and urban village models, distribution of land uses equally influences the GHG emissions. In the mono-centric cities, most economic activities and amenities are concentrated in the Central Business District (CBD). This promotes usage of public transportation, for most commuters travel from the suburbs to the CBD. In the polycentric cities, few jobs and amenities are located in the centre and most trips are made from suburb to suburb. Therefore, a large number of possible travel routes exist, but with few passengers per route. This makes public transportation expensive to operate thus private means of transportation become convenient options for users.

The composite (multiple-nucleic) urban form manifesting a dominant centre with many jobs located in the suburb's minor centres is the most common urban spatial structure. In the model, most trips from the suburbs to the CBD are made using public transportation, while trips from suburb to suburb are made using private modes of transportation. This necessitates the need for both public and private modes of transportation. The urban village model is utopian and is a creation of the urban master plans. In this scenario, urban areas contain many business centres and a commuter travel to the centre closest to them, granting more opportunities to walk and cycle to work. This model is ideal for it requires less transportation due to the reduced distances to work. This lowers the energy usage and the GHGs emission. Therefore, the more the urban spatial structure encourages public transportation, the more it leads to less emission of GHGs and *vice versa*. The above annunciations corroborate the correlation between urban morphology, GHG emissions and air quality. However, the relationship is moderated by the quantity and quality of vegetation, which are carbon sinks within the urban landscape. According to Klaus *et al.* [5], polluted air accumulates in the built up areas due to convergence of air into the areas during the day for such areas are warm and acts as urban heat islands. At night, this is replaced by cool fresh air from adjacent cold neighbourhoods. It is therefore evident that urban air quality and surface temperature values is determined by urban structures, anthropogenic and physical process.

The effect of urbanisation on global warming and climate change has raised challenges to sustainable urbanization and efforts have been made to postulate theories and models explaining the relationships, with majority being descriptive rather than quantitative. However, it is quantitative models facilitated by geospatial techniques, which have a niche in aiding the validation of the correlation. The geospatial techniques further provide an efficient and effective method to the analysis and modelling of the urban air quality distribution with morphological variations as well as building an understanding on the contributions of urbanization, expanding industrialization and problems associated with high-density developments to global warming and climate change. This is imperative in aiding the formulation of urban environmental policies geared towards mitigating the ravages of global warming and climate change [2,6]. Inasmuch as there is concurrence among the scholars that there is a significant relationship existing between urban morphology and air quality, the fundamental question is to what extent is an individual morphological parameter determining the distribution of air quality within a city. It is this gap in knowledge that this study sought to fill by quantitatively modelling the relationship existing between the urban morphological variables of development density, land uses, biomass index and the air quality values of Nairobi city.

The study which was guided by the hypothesis that there is a significant relationship existing between urban morphology and the air quality establishes the strength of the relationships existing between and among the

 DOI: https://doi.org/10.30564/jees.v3i2.3289

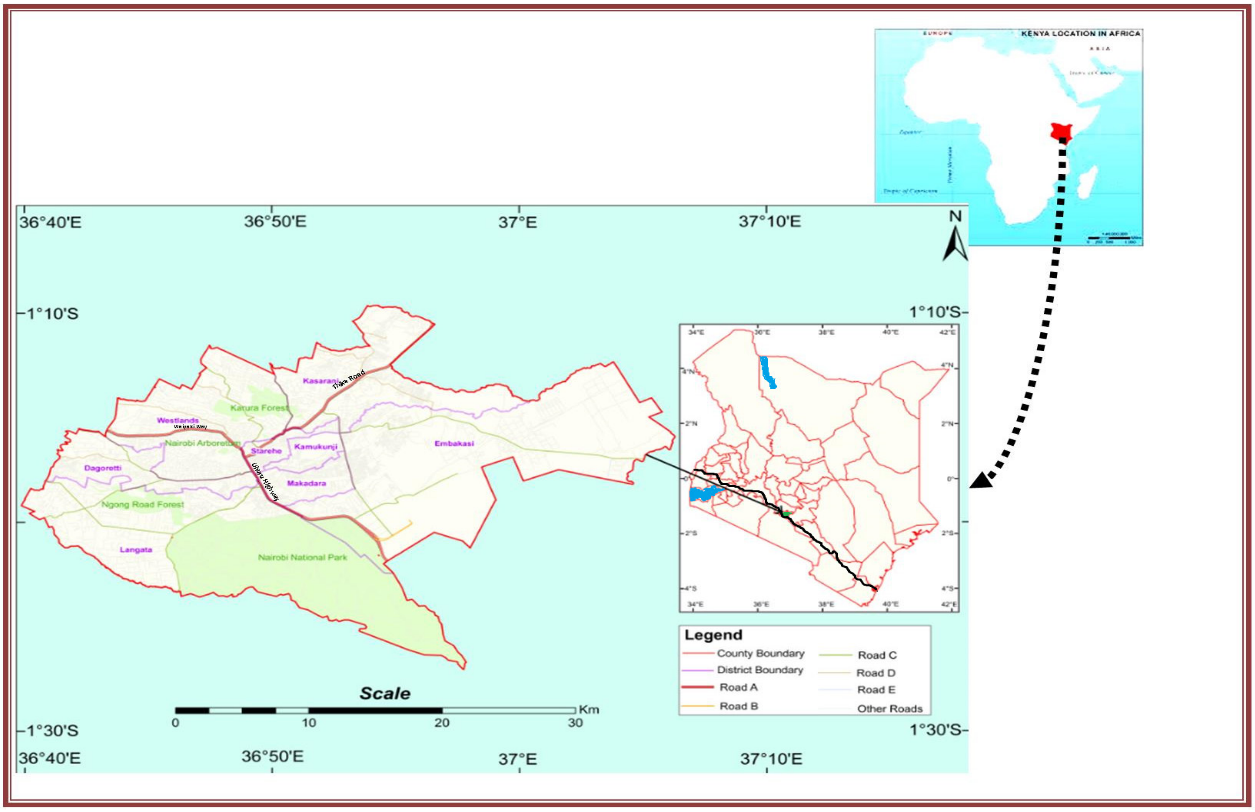

Figure 1. Location of the Study Area

urban morphological parameters of development density, land uses and biomass index and the air quality values of Nairobi city as derived from geospatial and *in-situ* measurements. This gives credence to urbanisation as a significant factor in global warming and climate change. To fulfil the aim of the study, wind velocity in the city was assumed constant throughout the year. Therefore, the distribution and the concentrations of the air pollutants within the city are only influenced by the amounts of the pollutants emitted by the point and mobile sources.

2. Methods and Materials

The study adopted both descriptive and quantitative designs to explain how air quality is distributed over Nairobi city and factors influencing the phenomenon. The study covered the entire Nairobi City County bounded by longitudes 36^0 40' and 37^0 10'E and latitudes 1^0 09' and 1^0 28'S covering an area of approximately 716 km^2 (Figure 1). While the independent variables of the study were urban morphological parameters of development density, land uses and biomass index, the dependent variable of the study was air quality (concentrations of carbon dioxide, sulphur dioxide, nitrogen dioxide and the suspended particulate matter) values. Biomass index was considered in this study as a morphological parameter because vegetation influences air quality through filtration, recycling and attenuation of wind velocity to influence the distribution of air pollutants [7,8]. However, the study did not consider water vapour, methane and ozone gases which are integral aspects of GHGs and the main drivers of global warming and climate change because the concentration of water vapour in the city is presumed to be uniform and determined by precipitation levels and not the anthropogenic activities. The ozone and methane gases are stratospheric layer gases thus could not be considered in this study, which relied on instruments whose validity and reliability are only guaranteed in the troposphere. The gases considered in the study are by-product of transportation and industrial fossil fuel combustion whose concentrations are subject to increase with urbanisation. Apart from the gases having noxious venom effect on human, animals and plants' health, the ability of the gases to form acid rain makes them destructive to vegetation, soil, construction materials and water bodies.

Building configuration exemplified by higher building densities and skyscrapers influence urban environmental quality through loss of natural vegetation alongside attenuation of wind velocity. This restricts air pollutants to urban canyons thus impeding pollution dispersal. Despite the significant role the building configuration plays in

DOI: https://doi.org/10.30564/jees.v3i2.3289

the determination of the urban air quality, it was not included in the study because the analysis of the building configuration requires up-to-date aerial photographs as opposed to satellite remote sensing utilised by the study. The constraint was in the acquisition of up-to-date aerial photographs of the city as the existing photographs are out-dated and provides incomplete spatial coverage of the city. Another limitation to the study was lack of air quality measuring stations in the city whose data could be utilised. This necessitated the use of *in-situ* approach for data capture, which is time consuming and expensive in terms of human resource involved, laboratory analysis and the cost of hiring the air samplers. Studies of this nature require more point data to support interpolation of the air quality values in the city.

2.1 Target Population and Sampling Procedures

All the 30 development zones prescribing development densities and land uses as detailed out by the Nairobi City County Government constituted the target population. Except for the air quality, sampling was not undertaken for the biomass index, development density and land uses.

2.2 Assessment of Development Density and Land Use Variations

Pre-processed and rectified multi-spectral IKONOS imagery of Bands 2, 3 and 4, covering the city together with the development-zoning map procured from the Nairobi City County Government were used for land use and development density analysis. The study area had to be extracted from the IKONOS imagery for the procured imagery covered the city and its environs. The analysis of development densities was undertaken through polygonisation of the developed surfaces from the extracted imagery. This was further overlain to development-zoning boundaries. The development densities were computed through aggregating areas of developed surfaces within a zone as a ratio of the zone's area. The computed densities for the 30 zones were further transformed into numerical (nominal) values ranging from 1 to 10. Since high development densities compromises air quality as compared to low densities, high development density zones were assigned low (1) numerical values while low density zones were assigned high (10) numerical values and spatially presented.

Visual image interpretation technique utilising the nine elements notably; shape, size, shadows, site, tone, texture, pattern, height and association was used to analyse land use distribution within the city and the identified land uses polygonised into a map. To assess the accuracy of the established land uses, random ground truthing aided by a hand-held GPS was undertaken. As informed by implications of the land uses on air quality, the identified land uses were assigned nominal values ranging from 1 to 10. Land uses such as industrial users known to compromise the air quality were assigned the lowest nominal values while forests and parks known for the enhancement of air quality were assigned higher nominal values. To arrive at a nominal value for a development zone based on land uses, proportion of a zone's area under different land uses were multiplied by the assigned nominal value of the land use and aggregation of the same undertaken per zone. This information is spatially presented inform of a map. This is similar to the procedure postulated by Nichol *et al* [9] when undertaking the assessment of urban environmental quality of Hong Kong city.

2.2.1 Determination of Biomass Index

Vegetation influences urban air quality due to its ability to purify the air and attenuate wind flow. However, it has been established that the biomass component of the vegetation is the most significant determinant of the degree to which vegetation influences ecosystem purification and energy flow. Remote sensing techniques for mapping urban vegetation parameters such as the total green spaces and the percentage of tree canopy combines higher resolution infrared imageries such as IKONOS, GEO-EYE, QUICK-BIRD with aerial photography and fieldwork. Although such methods are expensive, they present the best option for the medium resolution satellite imageries such as SPOT and Landsat lacks spatial details to detect fragmented urban vegetation [10]. As noted by Fung and Siu [11] who used Normalised Difference Vegetation Index for the assessment of Hong Kong city's vegetation change over time, Landsat imagery is only useful in conducting generalised surveys of green spaces and vegetation vigour, but fails to discriminate the vegetation type. The above being the case, IKONOS imagery as augmented by the zoning map of the city was utilised in facilitating the computation of the biomass index.

The clipping of the area constituting the city was undertaken from the multi-spectral IKONOS imagery upon which classification and polygonisation of the vegetation types were undertaken. To facilitate the computation of the Biomass Index (VD), the development zone boundaries were overlain on the generated vegetation cover map. The index for individual vegetation type was computed using equation 1 adopted from Nichol *et al* [9].

DOI: https://doi.org/10.30564/jees.v3i2.3289

$$\%VD = 100 \frac{W_v L_v}{L} / \sum W_v \quad (1)$$

Where: -

VD: Biomass Index

Wv : Weighting for each vegetation type v;

L$_v$: Area covered by a vegetation type v in a zone;

L: Total Area of a zone.

Averaging of biomass index for the development zones were undertaken and converted into numerical values ranging from 1 to 10 (Table 1). In acknowledging that vegetation covers with high biomass index impact positively on air quality, development zones with high average biomass index values were assigned higher (10) nominal values and *vice-versa* and spatially presented.

Table 1. Vegetation Weightings

Type	Weighting	Description
Short grass	0.2	Green grass lower than 0.5 m
Tall grass	0.4	Green grass higher than 0.5 m
Shrub	0.6	Short and woody plant with woody (non-green) stems from the base
Small Tree	0.7	Woody plant with trunk diameter < 0.3 m
Large Tree	0.9	Woody plant with trunk diameter > 0.3 m

Source:Adopted from Nichol *et al* [9]

2.3 The Assessment of the Spatial Variations of Air Quality within the City

Air sampling was undertaken to establish the concentrations of SPM, carbon dioxide, sulphur dioxide and nitrogen dioxide gases within the city. For the purposes of collecting air samples, sample sites were established through regular systematic point technique which involved the subdivision of the city into regular grids each measuring 8.0 square kilometres. Systematic random sampling technique of three grid intervals in all the directions was thereafter utilised in deciding the grid cells from whose centres air samples were picked [12]. Additionally, the coordinates of the sample sites were established using ArcGIS 10.5 Software. The identification of sample sites was done through hand held GPS. A total of 240 sample sites were established and air samples collected for laboratory analysis using Spectrex PAS-500 hand held air samplers. Granted that some zones such zone 20A (Karura Forest), 20G (Nairobi National Park), 20F (Jomo Kenyatta International Airport) and 20J (Ngong Forest) among others are homogeneous in terms of development densities and land uses, few samples were taken from the zones despite their larger sizes. Therefore, apart from the size of a development zone, decision on the number of sampling sites established per zone was further influenced by development densities and the heterogeneity of the land uses.

Laboratory readings for the gaseous concentrations were made for each sampled grid and averages computed by gas type per zone (Table 2). This was further converted into nominal values ranging from 1 to 10 with aggregate and average nominal values of the same computed per zone. Low gaseous concentrations were assigned higher (10) nominal values and *vice-versa*. Therefore, zones with high average gaseous concentration nominal values corresponded to zones of better air quality. The study adopted spatial interpolation technique, which relies on Geographical Information System to generate continuous surfaces from point measurements. The technique is premised on *Tobler's First Law of Geography* which states that *"The closer two points are, in space the more likely the points are similar and influence each other"*. As informed by simplicity, accuracy and sensitivity to clustering and presence of outliers, Inverse Distance Weighting (IDW) technique of

Table 2. Form Used for Recording Air Quality Values

Development Zones	Average Carbon Dioxide Values	Carbon Dioxide Nominal Values	Average Nitrogen Dioxide Values	Nitrogen Dioxide Nominal Values	Average Sulphur Dioxide Values	Sulphur Dioxide Nominal Values	Average Suspended Particulate Matter Values	Suspended Particulate Matter Nominal Values	Total Air Quality Nominal Values	Average Air Quality Nominal Value
1										
2										
3										
4										
.										
20J										

 DOI: https://doi.org/10.30564/jees.v3i2.3289

spatial interpolation was used in modelling the distribution of the gaseous concentrations into continues surfaces. In this technique, the weights of the measurements diminish as a function of distance, hence the name Inverse Distance Weighted technique [13]. While the results of the computations are presented in tabular format, the various gaseous concentrations are spatially presented using ArcGIS 10.5 Software.

2.4 Air Quality Model for the City

To arrive at a model explaining the spatial distribution of air quality in the city based on morphological variables under consideration, nominal values ranging from 1 to 10 were used (Table 3).

Bivariate and multivariate models were used in establishing the strengths of the relationships existing between the variables. This was done through the computation of the correlation coefficients (r) of the relationships. To determine the significance of the relationships and consistencies of the same, *t*-test and ANOVA were undertaken with levels of significance (α) and confidence being 5% and 95% respectively. In this endeavour, SPSS Software was used for statistical analysis. The correlation coefficients and the coefficients of determinations were calculated using *Pearson's Product Moment Correlation Coefficient Index* stated as function 2.

$$r = \frac{\sum[X-\dot{x}][Y-\dot{y}]}{\sqrt{\sum[X-\dot{x}]^2}\sqrt{\sum[Y-\dot{y}]^2}} \quad \text{...} (2)$$

Where: -

r = Correlation Coefficient

X = The Independent Variables

ẋ = The Mean of the Independent Variables

Y = The Dependent Variables

ẏ = The Mean of the Dependent Variables

The study concludes that there is no relationship existing between the variables if the established correlation coefficient (r) is zero. Similarly, if the correlation coefficient (r) value was established at between 0 and either -0.5 or 0.5, then it's concluded that there is a weak relationship existing between the variables. While the study concludes that there is fairly significant relationship existing between the variables if the established correlation coefficient (r) was either -0.5 or 0.5, the study concludes that there is a moderately significant relationship existing between the variables under consideration if the established correlation coefficient (r) ranges from either -0.5 to -0.7 or 0.5 to 0.7. Correlation coefficient (r) values ranging from either -0.7 to -1.0 or 0.7 to 1.0 are considered very significant.

Regression Models were established through equations 3, 4 and 5.

$$(\grave{Y} - \dot{y}) = \frac{(r)\delta Y[X-\dot{x}]}{\delta X} \quad \text{...} (3)$$

Where: -

Ỳ = Estimated Dependent Variable

r = Correlation Coefficient value

X = The Independent Variables

ẋ = The Mean of the Independent Variables

Y = The Dependent Variables

ẏ = The Mean of the Dependent Variables

δY = The standard deviation of the dependent

Table 3. Table Used for Correlating Air Quality with Urban Morphological Variables

Development Zones	Air Quality Nominal Values	Land Use Nominal Values	Development Density Nominal Values	Biomass Index Nominal Values
1				
2				
.				
.				
.				
.				
.				
.				
20J				

variables (Y)

δX = The standard deviation of the Independent variables (X)

The δY and δX are computed as:

$$\delta Y = \frac{\sqrt{\sum[Y-\bar{y}]^2}}{n-1} \qquad (4)$$

$$\delta X = \frac{\sqrt{\sum[X-\bar{x}]^2}}{n-1} \qquad (5)$$

Hence the regression model is stated as function 6

$$\Upsilon = a_1X_1 + a_2X_2 + a_3X_3 + a_4X_4 + a_5X_5 \ldots\ldots + \acute{\varepsilon} \qquad (6)$$

Where:

Υ = The urban air quality value

X_s= The independent variables

a_s = Coefficient of determinations of the independent variables

$\acute{\varepsilon}$ = The error term

The tests of significance of the established correlations were undertaken using *t*-test stated as either function 7(a) or 7(b).

$$t = \frac{r}{\sqrt{[1-r^2/n-2]}} \qquad (7a)$$

Or

$$t = \frac{(r)[\sqrt{n-2}]}{\sqrt{[1-r^2]}} \qquad (7b)$$

Where:

t = The calculated *t*-value

r = Correlation Coefficient Index

n = Sample Size

With level of significance (α) being 0.05 and the degree of freedom (df) being n-2, null (H_0) hypothesis was rejected if the calculated-*t* value was greater than the critical -*t* value. The ANOVA or the F-test facilitated the decisions as to whether the witnessed correlations occurred by chance or not (Table 4).

Table 4. The Analysis of Variance (ANOVA)

Source of Variation	Degree of Freedom	Sum of the Squares	Mean of the Squares
Accounted for by the Regression Line (SSR)	1	SSR =$\sum(\dot{Y}-\bar{y})^2$	SSR/1 SSR =$\sum(\dot{Y}-\bar{y})^2$
Accounted for by the Residuals (SSE)	n-2	SSE = $\sum(Y-\dot{Y})^2$	SSE/n-2 SSE = $\frac{\sum(Y-\dot{Y})^2}{n-2}$
Accounted for by the Mean (SST)	n-1	SST = $(Y-\bar{y})^2$	Nil

Source:Hammond and McCullagh [14].

The F-values were calculated using either function 8(a) or 8(b).

$$F = \frac{SSR/1}{SSE/n-2} \qquad (8a)$$

Or

$$F = \frac{\sum(\dot{Y}-\bar{y})^2}{\sum(Y-\dot{Y})^2/n-2} \qquad (8b)$$

With level of significance (α) being 0.05 and degree of freedom being n-2, the null hypothesis (H_0) was rejected if the calculated F-value was greater than the critical F-value.

2.5 Quality Assessment – Validity and Reliability

Validity of the information obtained in the study was safeguarded by pre-testing of data collection instruments, training of the Field Assistants on appropriate use of the instruments as well as proper data entry, particularly the data obtained through *in-situ* measurements. Equally, secondary information particularly the satellite imageries used in the study were procured from internationally accredited organisations notably from the United States Geological Survey (USGS) while the development zoning map and other allied maps were sourced from Nairobi City County Government and the Survey of Kenya. Reliability was achieved in the study by ensuring that the instruments used for *in-situ* measurements were granted equal exposure time. This was further accentuated by training of Research Assistants on accurate data capture and entry.

3. Results and Discussions

3.1 The Morphological Attributes of the City

Urban morphology, which is an embodiment of development densities, land uses, biomass index and building configurations among others affects urban air quality by attenuating wind circulation and generation of GHGs, consequently accentuating the concentration of air pollutants to heighten global warming and climate change. This realisation has brought forth the concept of urban sustainability, which incorporates ecological rationalisation in urban design and development. The concept has further provoked scholars to seek new models for redesigning the urban places. In this endeavour, four models of urban sustainability notably; neo-traditional development, urban containment, compact city and eco-city are currently being implemented in the cities. These models are based on seven main design concepts notably; the compactness, sustainable transportation, density, mixed land uses, diversity, passive solar design and greening.

  DOI: https://doi.org/10.30564/jees.v3i2.3289

3.1.1 The Land Uses of Nairobi City

The study established that by the year 2015 wetlands, parks and other recreational spaces, forests, commercial developments, airport land, industrial and residential developments, quarry land, urban agriculture, water bodies and riparian reserves, railway land, public purpose (educational institutions, hospitals and governmental offices) and undeveloped lands were the major land uses in the city (Table 5, Figure 2). Sizes of various land uses are computed in square kilometres per development zone (Table 6). This is collectively done with the computation of aggregate nominal values of the zones based on land uses and further spatially presented (Table 7, Figure 3).

Residential Land-Uses

Residential land-uses consisting of high, medium and low density habitations occupied 204.65 km^2 or 28.56% of the city's land. Even though this study did not dichotomise the residential land uses into these categories, high density residential developments consisting of areas with over 10,000 people per square kilometre are generally located in the north-eastern, south-eastern and south-western parts of the city as exemplified by Kariobangi, Dandora, Mathare, Kibera and Mukuruu neighbourhoods among others. As compared to low density residential neighbourhoods such as Karen, Muthaiga, Runda, Lavington, Kileleswa and Spring Valley which are inhabited by between 3,000 to 6,000 people per square kilometre, high density neighbourhoods are inadequately served by sanitation and drainage facilities making them environmental squalors. Most of the residential neighbourhoods in the city fall under medium density developments inhabited by between 6,000 to 10,000 people per square kilometre as exemplified by Langata, Kilimani, Embakasi and Buru-Buru neighbourhoods among others (See Appendix I for the development zones where the mentioned neighbourhoods fall).

The urban housing needs in Kenya is estimated at

Table 5. Proportions of Land Uses in the City by the Year 2015

	Land Uses	Area (km^2)	Percentages
1.	Residential Developments	204.65	28.56
	Industrial Developments		
2.	Secondary Industrial Developments	24.15	3.37
	Quarry Land	2.93	0.41
3.	**Commercial Developments**	41.29	5.76
	Transportation and Public Purpose Developments		
4.	Airport Land	17.44	2.43
	Railway Land	2.20	0.31
5.	**Public Purpose Lands:** Government Institutions, Hospitals, Schools, Universities, Colleges, Prisons and Military Barrack	20.97	2.93
	Recreational and Ecological Conservation Areas		
	Parks and Other Recreational Spaces	138.44	19.32
6.	Forests	26.45	3.69
	Wetlands	0.94	0.13
7.	**Public Utilities**		
	Water Bodies, Domestic and Waste Water Treatment Plants	3.81	0.53
	Deferred Land Uses		
8.	Urban Agriculture and Riparian Reserves	112.64	15.72
	Undeveloped Land	120.77	16.85
Total		716.22	100.00

200,000 units per annum, but only 30,000 units are being developed, resulting in an annual deficit of over 170,000 [15]. As accentuated by rapid urbanisation and inadequate budgetary provisions, the public and private sectors have not kept pace with the increasing demand. This has exposed the sector to market forces which are not sensitive to the needs of the middle and low-income cohorts, hence the continued mushrooming of informal settlements. This has further been exacerbated by lag in the expansion of housing infrastructure and serviced land, low purchasing power of the majority households, restrictive by-laws, inadequate access to housing finance and land policy allowing manipulation in tenure. Therefore, tackling housing deficit in the city requires reviewing policies which alienates the majority from accessing land.

Informal settlements in Nairobi have gradually grown since 1902 when European settlers appropriated large tracts of land in the environs of the city, consequently displacing indigenous inhabitants. While the colonialists made little provision for accommodating Africans in Nairobi, Africanisation policy after independence led to more Africans migrating into the city, consequently leading to the emergence of the informal settlements. According to Shihembesta [16], Kenyatta's administration allowed immigrants who could not find accommodation in the existing formal low-cost housing estates to put up temporary structures within the city as long as these structures were not too close to the CBD. Most of the houses in the informal settlements are single roomed with occupancy of over 6 inhabitants. This is not healthy for housing units having more than 2.5 people per habitable room are considered overcrowded [15]. In most cases, the informal settlements are established on flood plains, steep slopes, river banks and areas adjacent to sewers and dump sites where the inhabitants are increasingly exposed to health risks and disasters. Since slum demolition is justified by the Public Health Act (Cap 242), the inhabitants of such neighbourhoods are constantly under eviction threats and harassment.

Industrial Activities

Quarrying and manufacturing activities dominate the city's industrial sector. The need to enhance income and to reduce walking distance to the employment zones informed the *Nairobi Metropolitan Growth Strategy of 1973* which recommended restrictions on expansion of the then-existing industrial areas, but encouraged developments of additional seven secondary industrial areas next to residential neighbourhoods of Komarock, Ruaraka, Kariobangi, Dandora, off Mombasa road, North Airport road and off Outer Ring road (Figure 2). Since then, the city has witnessed expansion of industrial land

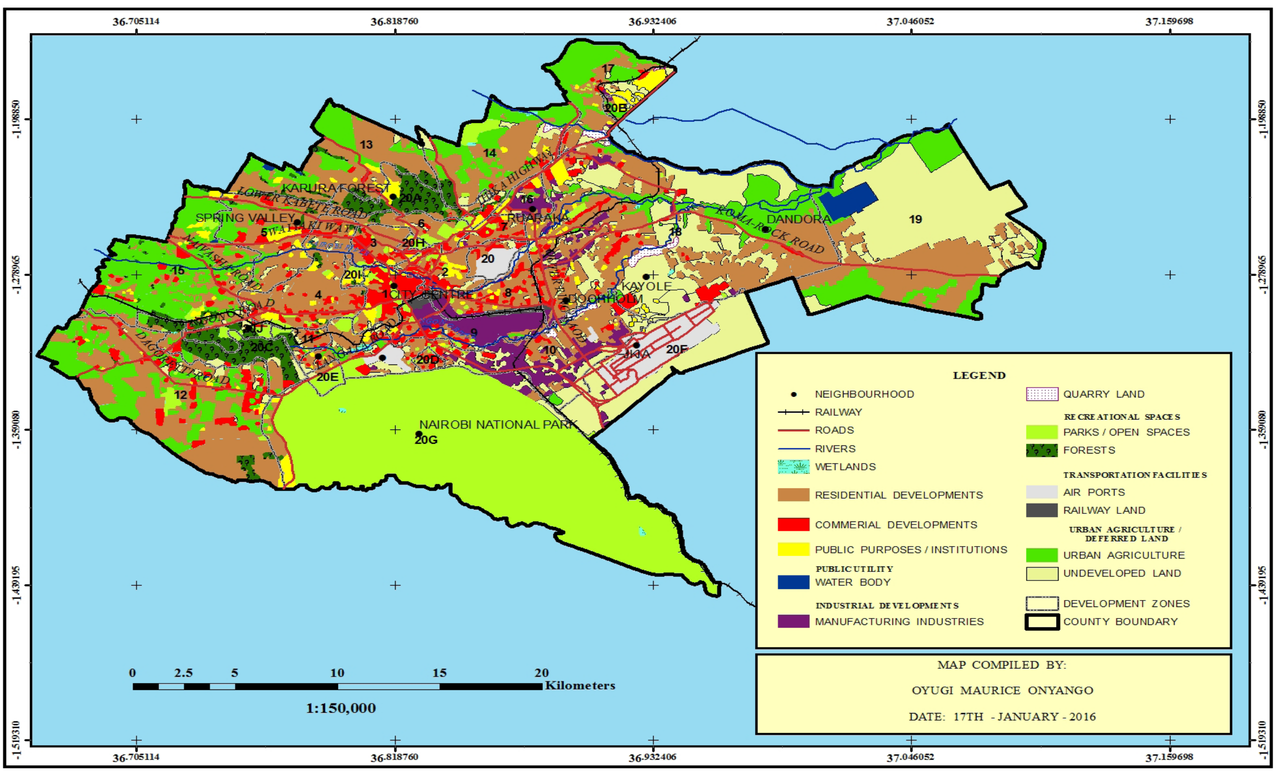

Figure 2. Land Uses of Nairobi in the Year 2015.

DOI: https://doi.org/10.30564/jees.v3i2.3289

uses which by the year 2015 stood at approximately 24.15 km^2 or 3.37% of the city's land. However, the industrial land uses are concentrated in the southern and eastern parts of the city; off and along Mombasa road, Kariobangi, Ruaraka, Dandora, Komarock, North Airport road and off Outer Ring road neighbourhoods. As attributed to vibrant construction industry, which has hiked the demand for building stones, quarrying has emerged with greater environmental concern in the city, particularly in the eastern and north-eastern neighbourhoods such as Kahawa, Kayole, Mwiki, Kasarani, Njiru and Ruai. By the year 2015, the land use occupied approximately 2.93 km^2 or 0.41% of the city's land. Apart from reducing the air quality through exacerbating smoke and dust pollutions as well as reducing aesthetic value of the human settlements, the explosives used in quarrying is a major source of noise pollution in the neighbourhoods where the quarries are situated.

Commercial and Service Centres

Apart from the commercial activities in the CBD, the *Nairobi Metropolitan Growth Strategy of 1973* recommended the development of seven other satellite commercial centres next to the industrial areas, which were proposed by the strategy. The strategy further recommended implementation of new housing schemes with at least a commercial centre. Currently, commercial land uses occupy approximately 41.29 km^2 or 5.76% of the city's land. These include the CBD, Westlands, Capitol Hill, Ngara areas, Eastleigh, Buru-Buru and Dagoretti Corner among others.

Public Purpose Land-Uses

Institutional land uses which are spread across the city include airports, airfields, railway land and institutions such as the hospitals, schools, universities, colleges, prisons and military barracks. Collectively these land uses occupy approximately 40.61 km^2 or 5.67% of the city's land.

Recreational and Ecological Conservation Areas

Parks and other Recreational Spaces

The city's biodiversity which is carbon sinks, moderators of urban micro-climates and provider of support to environmental education and biodiversity conservation programmes are constantly threatened by land fragmentation, degradation, overexploitation and pollution. The city's biodiversity has been sustained by favourable local ecological conditions such as high altitude, rainfall and fertile soils. The major parks and recreational spaces in the city include the Nairobi National Park, City Park and other minor recreational spaces such as the Uhuru Park, Jamhuri and Jeevanjee Gardens as well as Nyayo, Kasarani and City stadia which collectively occupy 138.44 km^2 or 19.32% of the city's land.

Forests

Nairobi city which was established on a mosaic landscape consisting of open grasslands, forests, woodlands and swamps has since been modified by anthropogenic activities with only small pockets of natural vegetation still remaining. Today the forests notably; Nairobi Arboretum, Karura, Ngong, Ololua and Dagoretti forests which have continued to play crucial roles as micro-climate moderators and water towers for the rivers within the city occupy 26.45 km^2 or 3.69% of the city's land. Karura forest is the water tower for Thigiri, Karura, Ruaraka and Gitathura rivers dissecting the northern parts of the city. The forest also supports plantation and indigenous trees which are sources of timber for domestic furniture and wood carvings. While Ngong forest which consists of planted and indigenous trees as well as grasslands was excised between the years 1963 to 1994 leaving it highly fragmented, the biodiversity of Ololua forest is under threats occasioned by mining activities. The Nairobi Arboretum has mainly been used for trials of plant species introduced in the country [17]. Illegal loggings targeting high-value tree species and allocations of parts of City park, Karura and Ngong forests to private developers have degraded and reduced the city's forests cover. In addition, implementation of the 60-meter wide southern by-pass road through Ngong forest has led to clearance of approximately 30 hectares of forest cover. This is likely to affect the city's air quality and microclimatic conditions [18]. The reduction of the forest cover has also been occasioned by weak enforcement of laws protecting the forests and budgetary constraints in the institutions responsible for forest management. For instance, the previous Forest Act (Cap.385) authorised the minister in charge of forests to gazette and/or de-gazette forest reserves without consultations. However, the Forest Act of 2005 has made the process more stringent [19].

Water Bodies and Wetlands

Apart from the rivers, other water bodies and wetlands in Nairobi are the Ruai waste water treatment plant and Nairobi dam. While water bodies cover approximately 3.81 km^2 or 0.53% of the city's land, wetlands cover approximately 0.94 km^2 or 0.13% of the city's land.

Continued discharge of untreated waste water and surface run-offs from municipal, industrial and agricultural land uses have increasingly polluted and eutrophicated the water bodies and wetlands. For example, Nairobi dam which was constructed in 1953 with a surface area and storage capacity of 350,000 m^2 and 98,000 m^3 respectively is currently shallow with an average depth of 2.76 metres. The reduction in the depth is attributed to silting of the dam as occasioned by inflow from the Ngong river and other surface run-offs from the Kibera settlement. While the water hyacinth, which has clogged the dam, has prevented recreational sailing and fishing which were the intended purposes for the construction of the dam, the scenario has further been complicated by the reclamation of sections of the dam for agricultural purposes through dumping of the solid wastes.

Agricultural and Deferred Land Uses

Urban agriculture has continued to manifest in the city through livestock rearing, cultivation of crops, fodder and horticulture as well as tree nurseries. Approximately 112.64 km^2 or 15.72% of land in Nairobi is under agriculture, with farming activities taking place along railway and road reserves, within flood plains and backyards of low density residential neighbourhoods, unutilized industrial plots and in the peri-urban areas where land holdings are large enough to accommodate cultivation and livestock rearing. While urban agriculture presents opportunities for alternative livelihood, it has adverse environmental impacts notably; upsurge of zoonotic diseases and chemical poisoning. Unattended livestock consume industrial effluents contaminated with heavy metals, which often end up in the food chain. Farmers in Nairobi also block open sewers to irrigate their crops, and thus predispose consumers of such products to pathogens and contamination with heavy metals. Chicken, goats and cattle reared in the informal settlements and urban peripheries contribute to waste volumes in form of dung. Kenya is lacking policies on urban agriculture yet she is a signatory to the *Harare Declaration of 2003* on urban and peri-urban agriculture in Eastern and Southern Africa, which recommends enactment of policies integrating urban agriculture into the urban economies. Moreover, this is contrary to the stipulations of the National Land Policy and County Government Act of 2012, which advocates for multi-functional urban land uses. This has led to undesirable farming practices such as diversion of sewage, deliberate bursting of water pipes to harness water for irrigation, illegal invasion of open-spaces and conversion of the same into gardens [20].

The undeveloped land which covers approximately 120.77 km^2 or 16.85% of the city are commercial, residential and industrial properties not developed by the owners. The spatial concentration of the parcels in the eastern and north-eastern parts of the city is attributed to the share certificate tenure system under which the majority of these properties belong. This tenure system involves land acquisition through joint purchase by the land buying companies, cooperatives, trusts, societies and self-help groups, which thereafter issue share certificates to the members. However, land speculations by these organizations make them hold the tenure documents for long at the detriment of the members who end up lacking documents to facilitate the approvals of their proposed developments by the city authority. Under such circumstances, land remains undeveloped for long periods - a phenomenon which is further compounded by individuals and companies who have bought land in these neighbourhoods for speculations.

3.1.2 Development Density and Biomass Variations within the City

Development densities vary across the city. For instance, CBD (Zone 1) and Eastlands (Zones 7, 8, 16 and 20) have the highest densities of 56.71%, 57.67%, 57.02%, 53.87% and 53.81% respectively. However, there are marked differences even within the same zone. For example, Zone 11 comprising of Kibera, Ayany, Olympic, Fort Jesus and Karanja neighbourhoods collectively have a density of 33.06% while Kibera neighbourhood; an informal settlement within the zone has a higher density of 87% (Table 8, Figure 4). Since high densities reduces the vegetation cover, such neighbourhoods experience high concentrations of air pollutants. Even though air purification abilities of the vegetation are influenced by vegetation type and density, it is the biomass component, which significantly influences the same. Findings on biomass index and aggregate morphological variations in the city are herein presented (Table 9, Figure 5, Table 10, Figure 6).

DOI: https://doi.org/10.30564/jees.v3i2.3289

Table 6. Land Uses in Square Kilometres by Zones

Development Zones	Wetlands	Parks and Other Recreational Spaces	Forests	Commercial Developments	Airport Land	Industrial Developments	Residential Developments	Quarry Land	Undeveloped Land	Urban Agriculture	Water Body	Railway Land	Public Purposes	TOTAL
1	0.00	1.12	0.08	4.27	0.00	0.00	1.41	0.00	0.08	0.00	0.00	0.01	1.14	8.10
2	0.00	0.46	0.00	2.30	0.13	0.01	3.01	0.00	0.35	0.00	0.00	0.05	0.99	7.28
3	0.00	0.38	0.06	1.85	0.00	0.00	3.52	0.00	0.01	0.00	0.00	0.00	0.37	6.20
4	0.00	0.81	0.59	3.07	0.00	0.00	14.45	0.00	0.48	0.19	0.00	0.00	1.23	20.82
5	0.00	0.03	0.82	1.68	0.00	0.00	11.20	0.00	0.46	3.40	0.00	0.00	1.56	19.16
6	0.00	1.20	0.73	0.47	0.00	0.00	3.73	0.00	0.21	0.00	0.00	0.00	0.39	6.75
7	0.00	0.16	0.01	1.45	0.00	0.13	1.62	0.00	0.25	0.00	0.00	0.00	0.42	4.03
8	0.00	0.25	0.00	2.47	0.46	1.25	4.67	0.00	0.33	0.00	0.00	1.00	0.34	10.76
9	0.00	0.50	0.00	1.81	0.02	7.07	2.20	0.06	0.37	0.14	0.00	0.99	0.15	13.31
10	0.31	2.25	0.02	2.95	2.24	8.28	11.56	0.65	9.14	1.62	0.00	0.00	0.76	39.78
11	0.00	0.36	0.63	0.47	0.00	0.00	1.36	0.00	0.29	0.15	0.00	0.00	0.09	3.34
12	0.00	1.03	1.31	5.08	0.00	0.00	31.70	0.00	1.48	18.96	0.05	0.00	0.98	60.59
13	0.00	0.00	2.55	0.33	0.00	0.00	14.80	0.00	0.30	9.18	0.26	0.00	0.86	28.27
14	0.24	2.09	1.47	0.98	0.00	0.00	11.41	0.26	2.00	9.89	0.00	0.00	0.74	29.08
15	0.00	0.61	1.71	2.24	0.00	0.00	8.73	0.00	0.33	25.45	0.07	0.00	1.50	40.64
16	0.00	0.00	0.08	0.31	0.00	1.75	0.99	0.00	0.41	0.24	0.00	0.00	0.63	4.40
17	0.00	0.13	0.00	0.62	0.00	0.19	4.94	0.66	1.83	9.41	0.00	0.00	2.19	19.97
18	0.14	0.62	0.00	6.52	0.02	3.80	42.21	1.30	38.13	15.66	0.04	0.16	3.00	111.60
19	0.00	0.00	0.00	0.00	0.00	0.00	21.91	0.00	41.59	16.27	3.39	0.00	0.00	83.15
20	0.00	0.00	0.00	0.70	2.45	0.00	1.09	0.00	0.25	0.00	0.00	0.00	0.00	4.49
20A	0.00	0.01	6.33	0.14	0.00	0.00	2.31	0.00	0.35	0.16	0.00	0.00	0.83	10.13
20B	0.00	0.00	0.00	0.01	0.00	0.06	0.32	0.00	0.07	0.47	0.00	0.00	0.58	1.51
20C	0.03	0.31	7.21	0.71	0.00	0.00	2.14	0.00	1.02	1.00	0.00	0.00	0.00	12.46
20D	0.00	0.21	0.00	0.48	0.00	0.00	0.52	0.00	0.15	0.00	0.00	0.00	0.00	1.36
20E	0.00	1.69	0.00	0.00	0.00	0.00	0.38	0.00	0.18	0.00	0.00	0.00	0.05	2.30
20F	0.00	0.16	0.00	0.07	12.12	0.42	0.05	0.00	19.19	0.00	0.00	0.00	0.06	32.07
20G	0.21	122.55	0.11	0.07	0.00	1.20	1.72	0.00	1.28	0.39	0.00	0.00	1.34	128.87
20H	0.00	0.44	0.00	0.04	0.00	0.00	0.32	0.00	0.00	0.00	0.00	0.00	0.11	0.91
20I	0.00	0.19	0.10	0.04	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.63	1.29
20J	0.00	0.86	2.64	0.15	0.00	0.00	0.07	0.00	0.24	0.06	0.00	0.00	0.04	4.05
Total	**0.94**	**138.44**	**26.45**	**41.29**	**17.44**	**24.15**	**204.65**	**2.93**	**120.77**	**112.64**	**3.81**	**2.20**	**20.97**	**716.68**

 DOI: https://doi.org/10.30564/jees.v3i2.3289

Table 7. Land Use Nominal Values

Development Zones	Wetlands (9.0)	Parks and Other Recreational Spaces (8.0)	Forests (10.0)	Commercial Developments (3.0)	Airport Land (4.0)	Industrial Developments (1.0)	Residential Developments (2.0)	Quarry Land (1.0)	Undeveloped Land (7.0)	Urban Agriculture (6.0)	Water Body (6.5)	Railway Land (4.5)	Public Purposes (5.0)	Total (Zonal) Nominal Values
1	0.00	1.11	0.10	1.58	0.00	0.00	0.35	0.00	0.07	0.00	0.00	0.00	0.71	3.91
2	0.00	0.51	0.00	0.95	0.07	0.00	0.83	0.00	0.33	0.00	0.00	0.03	0.68	3.39
3	0.00	0.49	0.10	0.90	0.00	0.00	1.13	0.00	0.02	0.00	0.00	0.00	0.30	2.94
4	0.00	0.31	0.29	0.44	0.00	0.00	1.39	0.00	0.16	0.06	0.00	0.00	0.29	2.94
5	0.00	0.01	0.43	0.26	0.00	0.00	1.17	0.00	0.17	1.07	0.00	0.00	0.41	3.52
6	0.00	1.43	1.09	0.21	0.00	0.00	1.11	0.00	0.22	0.00	0.00	0.00	0.29	4.34
7	0.00	0.32	0.01	1.08	0.00	0.03	0.81	0.00	0.43	0.00	0.00	0.00	0.52	3.19
8	0.00	0.19	0.00	0.69	0.17	0.12	0.87	0.00	0.21	0.00	0.00	0.42	0.16	2.82
9	0.00	0.31	0.00	0.41	0.01	0.53	0.33	0.01	0.19	0.06	0.00	0.33	0.05	2.23
10	0.07	0.45	0.01	0.22	0.23	0.21	0.58	0.02	1.61	0.24	0.00	0.00	0.10	3.73
11	0.00	0.86	1.88	0.42	0.00	0.00	0.81	0.00	0.62	0.26	0.00	0.00	0.13	4.99
12	0.00	0.14	0.22	0.25	0.00	0.00	1.05	0.00	0.17	1.88	0.01	0.00	0.08	3.78
13	0.00	0.00	0.90	0.04	0.00	0.00	1.05	0.00	0.07	1.95	0.06	0.00	0.15	4.22
14	0.07	0.57	0.50	0.10	0.00	0.00	0.78	0.01	0.48	2.04	0.00	0.00	0.13	4.70
15	0.00	0.12	0.42	0.17	0.00	0.00	0.43	0.00	0.06	3.76	0.01	0.00	0.18	5.15
16	0.00	0.00	0.17	0.21	0.00	0.40	0.45	0.00	0.65	0.33	0.00	0.00	0.71	2.92
17	0.00	0.05	0.00	0.09	0.00	0.01	0.49	0.03	0.64	2.83	0.00	0.00	0.55	4.70
18	0.01	0.04	0.00	0.18	0.00	0.03	0.76	0.01	2.39	0.84	0.00	0.01	0.13	4.41
19	0.00	0.00	0.00	0.00	0.00	0.00	0.53	0.00	3.50	1.17	0.26	0.00	0.00	5.47
20	0.00	0.00	0.00	0.47	2.19	0.00	0.48	0.00	0.38	0.00	0.00	0.00	0.00	3.52
20A	0.00	0.01	6.25	0.04	0.00	0.00	0.46	0.00	0.24	0.10	0.00	0.00	0.41	7.50
20B	0.00	0.01	0.00	0.01	0.00	0.04	0.43	0.00	0.34	1.86	0.00	0.00	1.91	4.60
20C	0.03	0.21	5.79	0.17	0.00	0.00	0.34	0.00	0.57	0.48	0.00	0.00	0.00	7.60
20D	0.00	1.24	0.00	1.07	0.00	0.00	0.76	0.00	0.76	0.00	0.00	0.00	0.00	3.83
20E	0.00	5.87	0.00	0.00	0.00	0.00	0.33	0.00	0.54	0.00	0.00	0.00	0.12	6.86
20F	0.00	0.04	0.00	0.01	1.51	0.01	0.00	0.00	4.19	0.00	0.00	0.00	0.01	5.77
20G	0.02	7.61	0.01	0.00	0.00	0.01	0.03	0.00	0.07	0.02	0.00	0.00	0.05	7.81
20H	0.00	3.89	0.00	0.12	0.00	0.00	0.70	0.00	0.00	0.00	0.00	0.00	0.63	5.34
20I	0.00	1.15	0.76	0.09	0.00	0.00	0.52	0.00	0.00	0.00	0.00	0.00	2.46	4.98
20J	0.00	1.69	6.51	0.11	0.00	0.00	0.04	0.00	0.42	0.09	0.00	0.00	0.05	8.89

DOI: https://doi.org/10.30564/jees.v3i2.3289

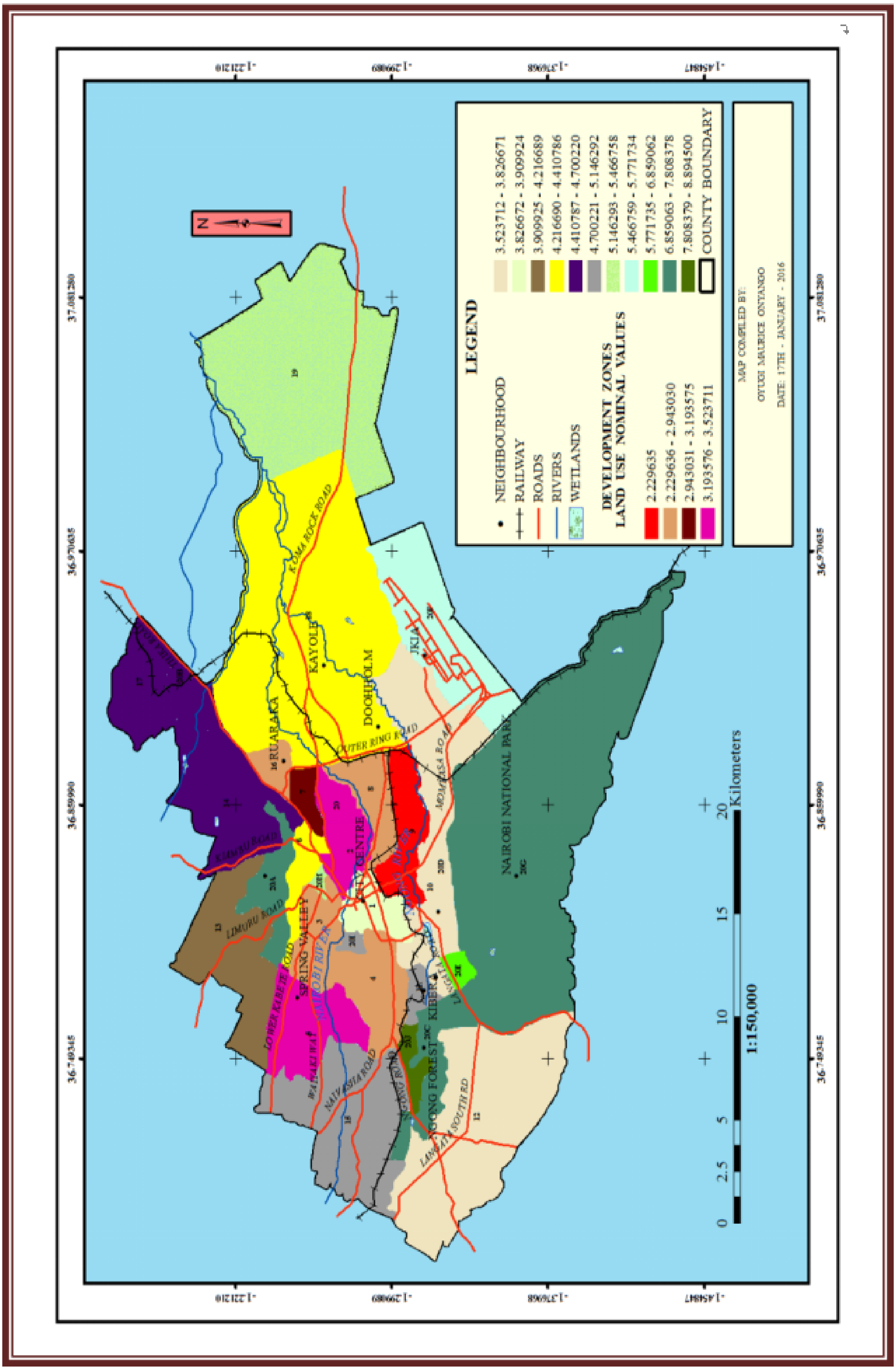

Figure 3. The Spatial Distribution of Land Use Nominal Values

Table 8. Nominal Values for the Development Densities in the City

Development Zones	Built-Up Land Uses by Areas (km^2)						The Zone's Total Land Areas (km^2)	Actual Built Up Spaces - Areas (km^2)	Development Density (%)	Development Density Nominal Value
	Commercial Developments	Airport Land	Industrial Developments	Residential Developments	Railway Land	Public Purposes				
1	4.27	0.00	0.00	1.41	0.01	1.14	8.10	4.59	56.71	4.5
2	2.30	0.13	0.01	3.01	0.05	0.99	7.28	3.59	49.32	5.5
3	1.85	0.00	0.00	3.52	0.00	0.37	6.20	3.01	48.56	5.5
4	3.07	0.00	0.00	14.45	0.00	1.23	20.82	5.84	28.04	7.5
5	1.68	0.00	0.00	11.20	0.00	1.56	19.16	4.49	23.45	8.0
6	0.47	0.00	0.00	3.73	0.00	0.39	6.75	1.15	17.05	8.5
7	1.45	0.00	0.13	1.62	0.00	0.42	4.03	2.32	57.67	4.5
8	2.47	0.46	1.25	4.67	1.00	0.34	10.76	6.14	57.02	4.5
9	1.81	0.02	7.07	2.20	0.99	0.15	13.31	8.90	66.88	3.5
10	2.95	2.24	8.28	11.56	0.00	0.76	39.78	16.49	41.47	6.0
11	0.47	0.00	0.00	1.36	0.00	0.09	3.34	1.10	33.06	7.0
12	5.08	0.00	0.00	31.70	0.00	0.98	60.59	10.05	16.58	8.5
13	0.33	0.00	0.00	14.80	0.00	0.86	28.27	4.00	14.14	9.0
14	0.98	0.00	0.00	11.41	0.00	0.74	29.08	3.28	11.29	9.0
15	2.24	0.00	0.00	8.73	0.00	1.50	40.64	4.36	10.73	9.0
16	0.31	0.00	1.75	0.99	0.00	0.63	4.40	2.37	53.87	5.0
17	0.62	0.00	0.19	4.94	0.00	2.19	19.97	4.19	20.96	8.0
18	6.52	0.02	3.80	42.21	0.16	3.00	111.60	28.17	25.24	8.0
19	0.00	0.00	0.00	21.91	0.00	0.00	83.15	10.95	13.17	9.0
20	0.70	2.45	0.00	1.09	0.00	0.00	4.49	2.42	53.81	5.0
20A	0.14	0.00	0.00	2.31	0.00	0.83	10.13	0.92	9.04	9.5
20B	0.01	0.00	0.06	0.32	0.00	0.58	1.51	0.54	35.87	6.5
20C	0.71	0.00	0.00	2.14	0.00	0.00	12.46	1.00	8.03	9.5
20D	0.48	0.00	0.00	0.52	0.00	0.00	1.36	0.64	47.50	5.5
20E	0.00	0.00	0.00	0.38	0.00	0.05	2.30	0.22	9.69	9.5
20F	0.07	12.12	0.42	0.05	0.00	0.06	32.07	7.58	23.63	8.0
20G	0.07	0.00	1.20	1.72	0.00	1.34	128.87	1.69	1.31	10
20H	0.04	0.00	0.00	0.32	0.00	0.11	0.91	0.18	19.77	8.5
20I	0.04	0.00	0.00	0.33	0.00	0.63	1.29	0.35	27.30	7.5
20J	0.15	0.00	0.00	0.07	0.00	0.04	4.05	0.09	2.23	10.0

 DOI: https://doi.org/10.30564/jees.v3i2.3289

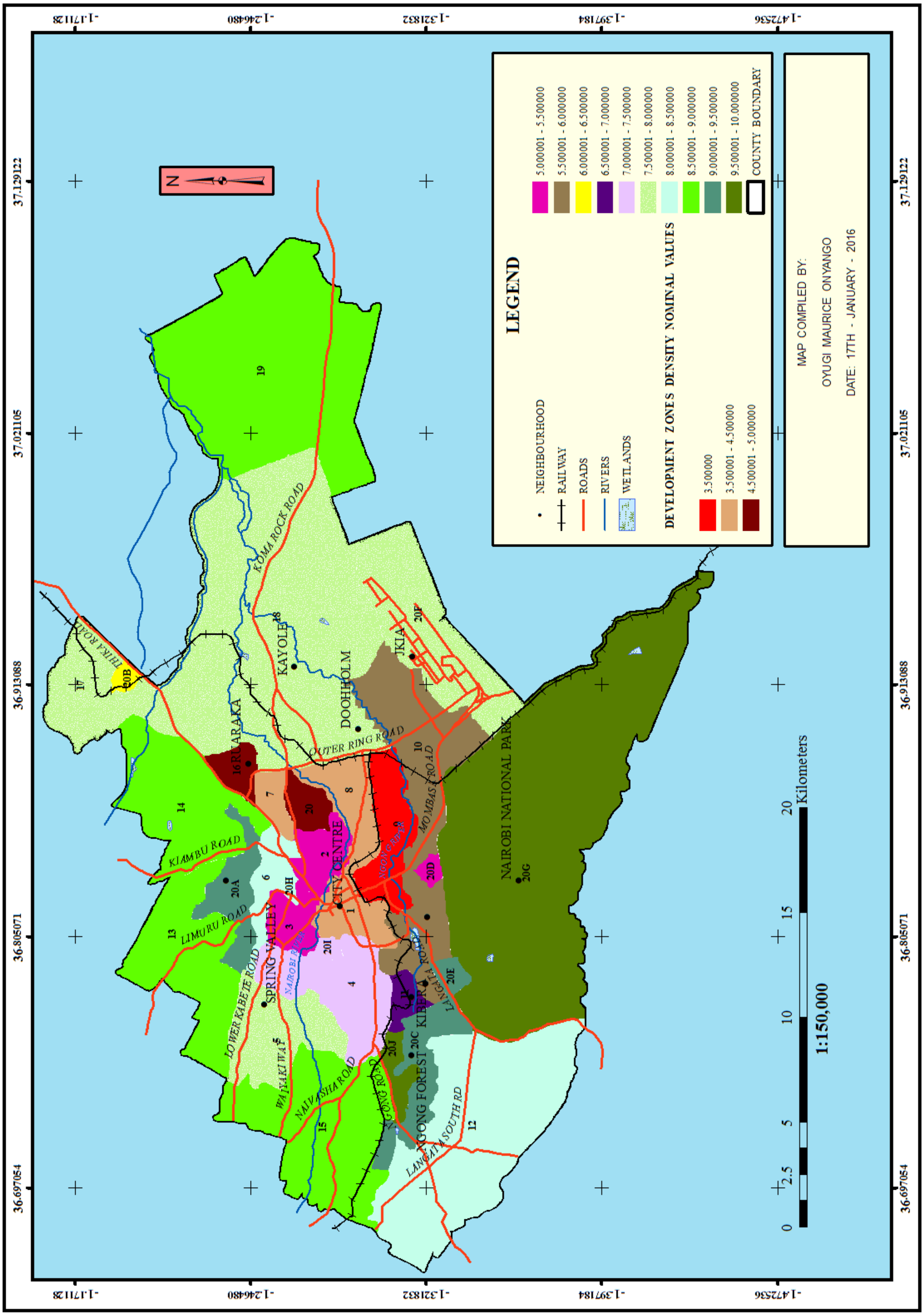

Figure 4. The Distribution of Development Density Nominal Values

Table 9. Biomass Variations within the City

Development Zones	Vegetation Categorization in the Un-built Spaces and Weightings									Actual Built Up Spaces (km^2)	Un-Built Spaces or the Open-Land (km^2)	The Zone's Total Land Areas (km^2)	The Zonal Aggregate Biomass Index (VD) (%)	The Biomass Index Nominal Value (Scale to 10: Aggregate VD/10)
	Wetlands (0.3)	Parks and Other Recreational Spaces (0.8)	Forests (1.0)	Quarry Land (0.1)	Undeveloped Land				Urban Agriculture (0.5)					
					Short grass (0.2)	Tall grass (0.4)	Shrub (0.6)	Small Tree (0.7)						
1	0.00	11.07	0.99	0.00	19.93				0.00	4.59	3.51	8.10	31.98	3.20
2	0.00	5.06	0.00	0.00	24.39				0.00	3.59	3.69	7.28	29.46	2.95
3	0.00	4.91	1.04	0.00	30.98				0.00	3.01	3.19	6.20	36.94	3.69
4	0.00	3.12	2.85	0.00	44.99				0.47	5.84	14.98	20.82	51.43	5.14
5	0.00	0.14	4.30	0.00	38.01				8.88	4.49	14.67	19.16	51.34	5.13
6	0.00	14.26	10.87	0.00	37.98				0.00	1.15	5.60	6.75	63.11	6.31
7	0.00	3.18	0.13	0.00	15.29				0.00	2.32	1.70	4.03	18.60	1.86
8	0.00	1.87	0.00	0.00	16.26				0.00	6.14	4.62	10.76	18.12	1.81
9	0.00	3.04	0.00	0.04	11.15				0.51	8.90	4.41	13.31	14.74	1.47
10	0.23	4.52	0.04	0.16	20.87				2.03	16.49	23.28	39.78	27.86	2.79
11	0.00	8.59	18.84	0.00	13.19				2.20	1.10	2.24	3.34	42.81	4.28
12	0.00	1.37	2.16	0.00	33.73				15.65	10.05	50.54	60.59	52.90	5.29
13	0.00	0.00	9.01	0.00	30.42				16.24	4.00	24.28	28.27	55.67	5.56
14	0.25	5.74	5.04	0.09	24.46				17.01	3.28	25.80	29.08	52.58	5.26
15	0.00	1.19	4.22	0.00	14.53				31.32	4.36	36.28	40.64	51.25	5.13
16	0.00	0.00	1.72	0.00	15.58				2.73	2.37	2.03	4.40	20.03	2.00
17	0.00	0.52	0.00	0.33	11.18				23.57	4.19	15.78	19.97	35.60	3.56
18	0.04	0.45	0.00	0.12	23.54				7.01	28.17	83.43	111.60	31.15	3.12
19	0.00	0.00	0.00	0.00	31.60				9.78	10.95	72.20	83.15	41.38	4.14
20	0.00	0.00	0.00	0.00	27.71				0.00	2.42	2.07	4.49	27.71	2.77
20A	0.00	0.09	62.45	0.00	18.75				0.81	0.92	9.21	10.13	82.09	8.21
20B	0.00	0.12	0.00	0.00	19.83				15.46	0.54	0.97	1.51	35.41	3.54
20C	0.08	2.11	57.91	0.00	16.16				4.03	1.00	11.46	12.46	80.29	8.03
20D	0.00	12.36	0.00	0.00	14.82				0.00	0.64	0.71	1.36	27.18	2.72
20E	0.00	58.73	0.00	0.00	6.76				0.00	0.22	2.08	2.30	65.49	6.55
20F	0.00	0.39	0.00	0.00	37.94				0.00	7.58	24.49	32.07	38.33	3.83
20G	0.05	76.07	0.09	0.00	1.82				0.15	1.69	127.18	128.87	78.19	7.82
20H	0.00	38.93	0.00	0.00	22.10				0.00	0.18	0.73	0.91	61.03	6.10
20I	0.00	11.55	7.57	0.00	35.49				0.00	0.35	0.94	1.29	54.61	5.46
20J	0.00	16.90	65.06	0.00	7.10				0.72	0.09	3.96	4.05	89.78	8.98

 DOI: https://doi.org/10.30564/jees.v3i2.3289

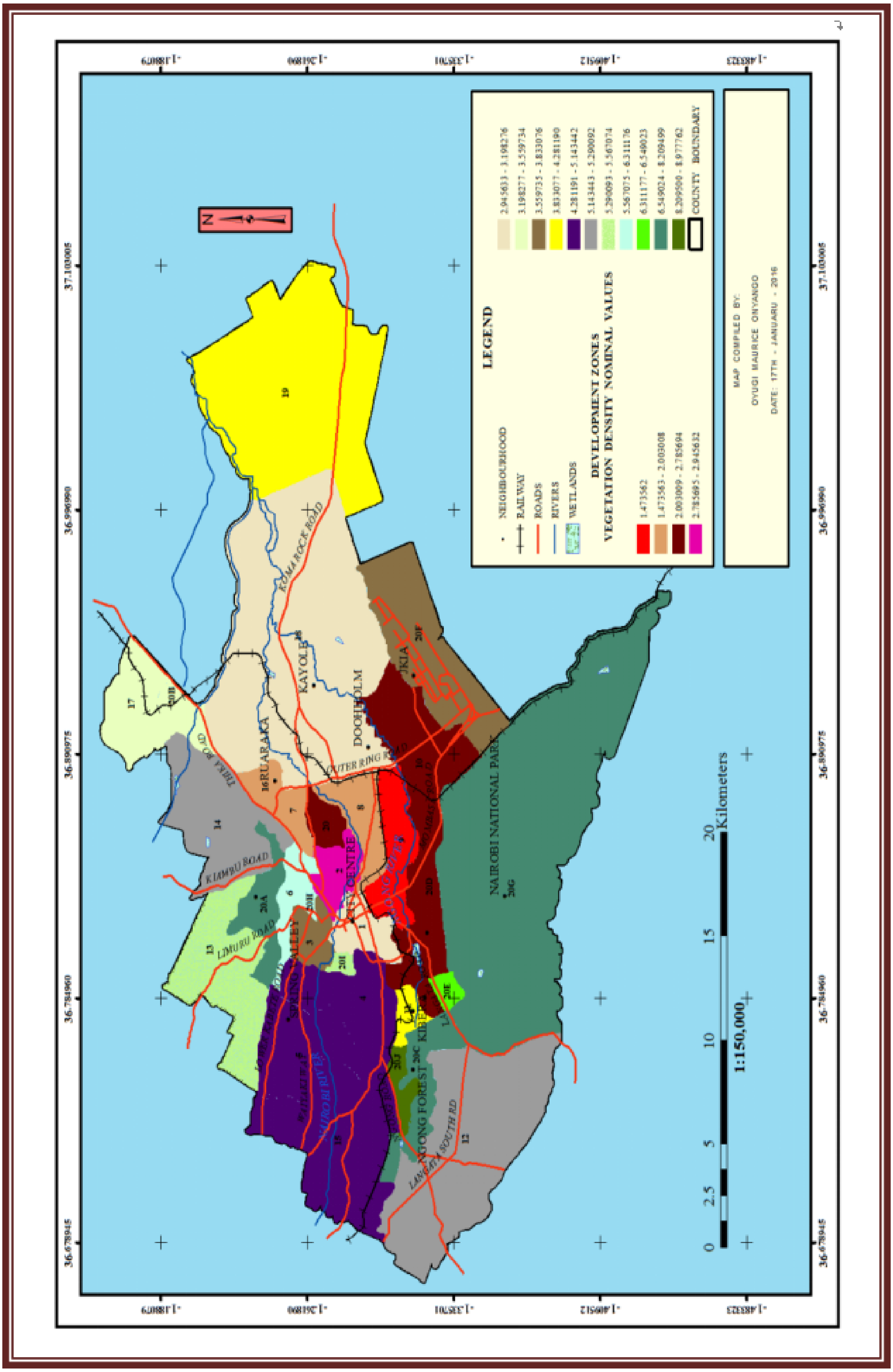

Figure 5. The Spatial Distribution of Biomass Values

Table 10. Morphological Variations within the City

Development Zones	Urban Form Nominal Values		Biomass Index Nominal Values (VDNV)	Aggregate Urban Morphology Nominal Values (DDNV+LUNV+VDNV)	Average Urban Morphology Nominal Values (DDNV+LUNV+VDNV)/3
	Development Density Nominal Value (DDNV)	Land Use Nominal Values (LUNV)			
1	4.5	3.91	3.20	11.61	3.87
2	5.5	3.39	2.95	11.84	3.95
3	5.5	2.94	3.69	12.14	4.05
4	7.5	2.94	5.14	15.58	5.19
5	8.0	3.52	5.13	16.65	5.55
6	8.5	4.34	6.31	19.15	6.38
7	4.5	3.19	1.86	9.56	3.18
8	4.5	2.82	1.81	9.13	3.04
9	3.5	2.23	1.47	7.20	2.40
10	6.0	3.73	2.79	12.51	4.17
11	7.0	4.99	4.28	16.27	5.42
12	8.5	3.78	5.29	17.57	5.86
13	9.0	4.22	5.57	18.78	6.26
14	9.0	4.70	5.26	18.96	6.32
15	9.0	5.15	5.13	19.27	6.42
16	5.0	2.92	2.00	9.93	3.31
17	8.0	4.70	3.56	16.26	5.42
18	8.0	4.41	3.12	15.53	5.18
19	9.0	5.47	4.14	18.60	6.20
20	5.0	3.52	2.77	11.29	3.76
20A	9.5	7.50	8.21	25.21	8.40
20B	6.5	4.60	3.54	14.64	4.88
20C	9.5	7.60	8.03	25.13	8.38
20D	5.5	3.83	2.72	12.04	4.01
20E	9.5	6.86	6.55	22.91	7.64
20F	8.0	5.77	3.83	17.60	5.87
20G	10.0	7.81	7.82	25.63	8.54
20H	8.5	5.34	6.10	19.94	6.65
20I	7.5	4.98	5.46	17.94	5.98
20J	10.0	8.89	8.98	27.87	9.29

DOI: https://doi.org/10.30564/jees.v3i2.3289

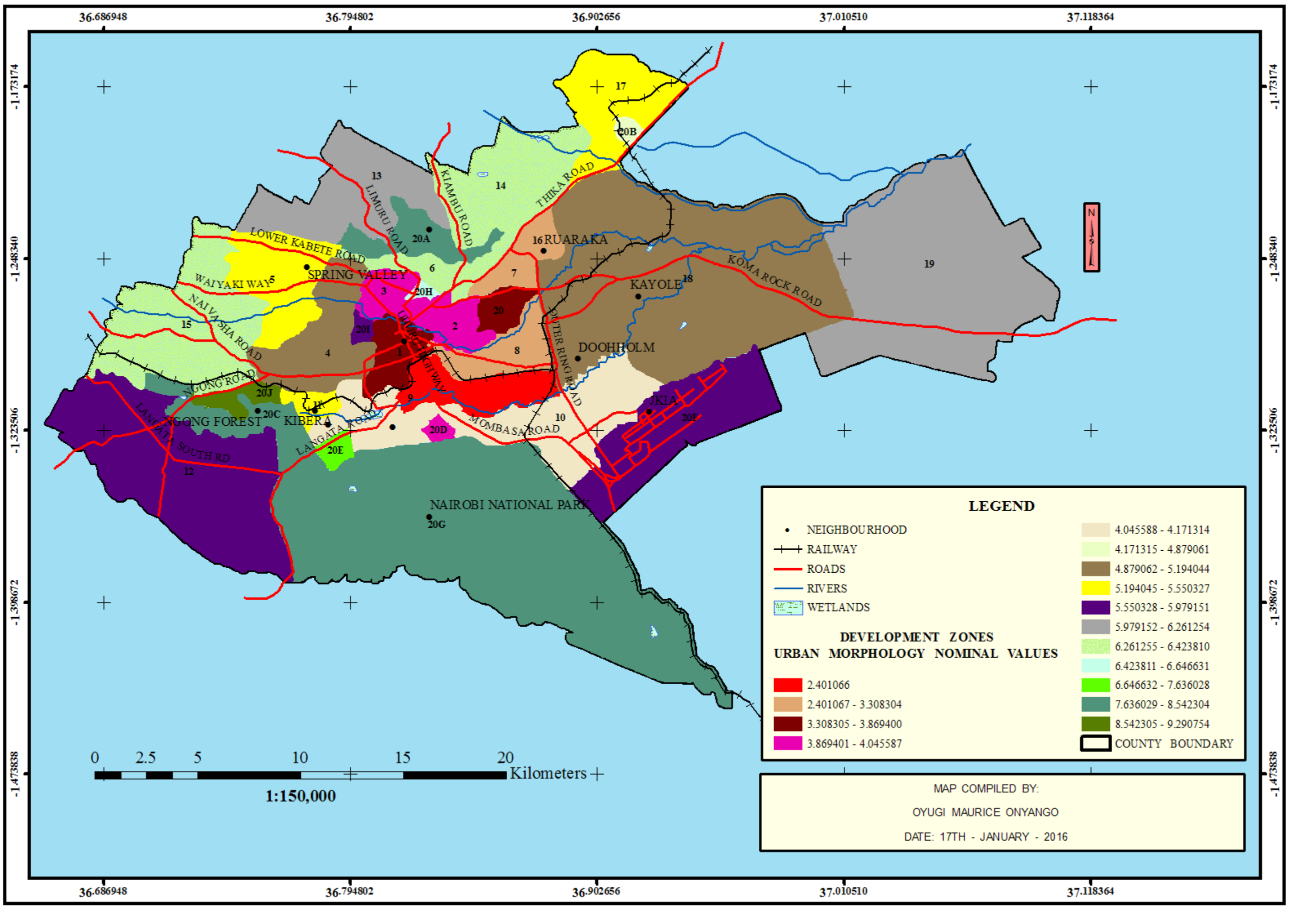

Figure 6. Spatial Distribution of Urban Morphological Values

3.2 Air Quality Distribution in the City

High urbanisation and improved economic growth rates as well as inadequate public transportation in African cities have contributed to increased vehicular volume and GHG emissions. Currently, out of the 8.5 million registered vehicles in Kenya, approximately 5.0 million operate within Nairobi and its environs. This has heightened traffic snarl and air pollution in the city, making Nairobi rank fourth globally in transportation problems. Should the trend continue, the number of vehicle trips would increase by 148% in the year 2025 while the average speed will reduce from 35 km/hour to 11 km/hour [21]. Motor vehicles emit GHGs, suspended particulate matter and Sulphur dioxide which react with sunlight to deplete the ozone layer. These pollutants also have health effects manifesting in chest congestion, coughs, phlegm, sore throats and asthmatic attacks [22,23]. Of all these pollutants, $SPM_{2.5}$ which is a complex mixture of solid and liquid organic and inorganic particles less than or equal to 2.5 μm in diameter is of particular significance on climate change and health effects. Their small sizes enable them to penetrate deeply into the lungs where they exert adverse effects such as lung and heart diseases as well as exacerbating post-neonatal infant mortality [24,25].

There is a marked gradual decrease in gaseous concentrations from the CBD, industrial areas and satellite commercial centres in the city, which are employment zones experiencing increased vehicular volume, heightening the concentration of air pollutants (Table 11). This is complicated by the high development densities characterising the neighbourhoods, which has depleted the vegetation cover as well as attenuating wind velocity, consequently reducing purification ability of the ecosystem and pollutants' dispersal. Carbon dioxide is the widest spread air pollutant within the city followed by nitrogen dioxide, sulphur dioxide and SPM respectively (Figures 7 to 10).

Table 11. Average Air Concentrations and Nominal Values by Development Zones

Development Zones	Average Carbon Dioxide Values (ppm)	Carbon Dioxide Nominal Values	Average Nitrogen Dioxide Values (ppb)	Nitrogen Dioxide Nominal Values	Average Sulphur Dioxide Values (ppb)	Sulphur Dioxide Nominal Values	Average Suspended Particulate Matter Values (μg/m^3).	Suspended Particulate Matter Nominal Values	Total Air Quality Nominal Value	Average Air Quality Nominal Values
1	375.33	1.333	21.87	4.333	1.40	5.000	43.72	7.000	17.666	4.417
2	375.16	1.333	24.08	3.667	1.36	5.000	41.88	7.000	17.000	4.250
3	268.42	4.667	12.93	7.000	0.80	7.667	23.36	8.333	27.667	6.917
4	324.03	3.000	11.68	7.333	0.67	8.333	12.48	9.333	27.999	7.000
5	199.48	7.000	6.32	9.000	0.37	9.667	7.57	10.000	35.667	8.917
6	234.17	5.667	12.58	7.000	0.80	7.667	18.03	9.000	29.334	7.334
7	318.51	3.000	21.46	4.333	1.47	4.667	55.38	6.000	18.0	4.500
8	398.68	1.000	29.32	1.667	1.81	3.000	84.29	3.667	9.334	2.334
9	401.97	1.000	28.97	2.000	1.82	3.000	78.62	4.000	10.0	2.500
10	362.63	2.000	27.61	2.333	1.76	3.333	76.64	4.333	11.999	3.000
11	358.55	2.000	13.64	6.667	0.84	7.333	11.65	9.333	25.333	6.333
12	135.57	8.667	6.62	9.000	0.36	9.667	10.80	9.667	37.001	9.250
13	124.55	9.333	4.60	9.667	0.37	9.667	8.51	9.667	38.334	9.584
14	189.89	7.333	11.33	7.333	0.81	7.667	27.18	8.333	30.666	7.667
15	174.45	7.667	7.29	9.000	0.44	9.333	12.60	9.333	35.333	8.833
16	263.74	4.667	17.35	5.667	1.24	5.667	49.03	6.333	22.334	5.584
17	210.28	6.333	10.68	7.667	0.72	8.000	21.97	8.667	30.667	7.667
18	260.83	5.000	16.33	6.000	1.21	5.667	51.32	6.333	23.0	5.750
19	202.16	6.667	11.15	7.667	0.57	8.667	32.43	7.667	30.668	7.667
20	371.94	1.667	26.71	2.667	1.72	3.333	73.53	4.333	12.0	3.000
20A	145.38	8.667	6.73	9.000	0.49	9.000	11.59	9.333	36.0	9.000
20B	201.79	6.667	8.66	8.333	0.76	7.667	17.05	9.000	31.667	7.917
20C	237.67	5.667	7.54	8.667	0.50	9.000	10.80	9.667	33.001	8.250
20D	361.00	2.000	25.15	3.000	1.55	4.333	51.22	6.333	15.666	3.917
20E	272.34	4.667	13.65	6.667	0.86	7.333	10.41	9.667	28.334	7.084
20F	278.58	4.333	21.94	4.333	1.27	5.333	68.30	5.000	18.999	4.750
20G	247.04	5.333	19.47	5.000	0.94	7.000	44.59	6.667	24.0	6.000
20H	290.37	4.000	16.37	6.000	1.03	6.667	24.30	8.333	25.0	6.250
20I	333.16	2.667	15.39	6.333	0.85	7.333	18.96	8.667	25.0	6.250
20J	282.26	4.333	7.34	9.000	0.49	9.000	12.55	9.333	31.666	7.917

 DOI: https://doi.org/10.30564/jees.v3i2.3289

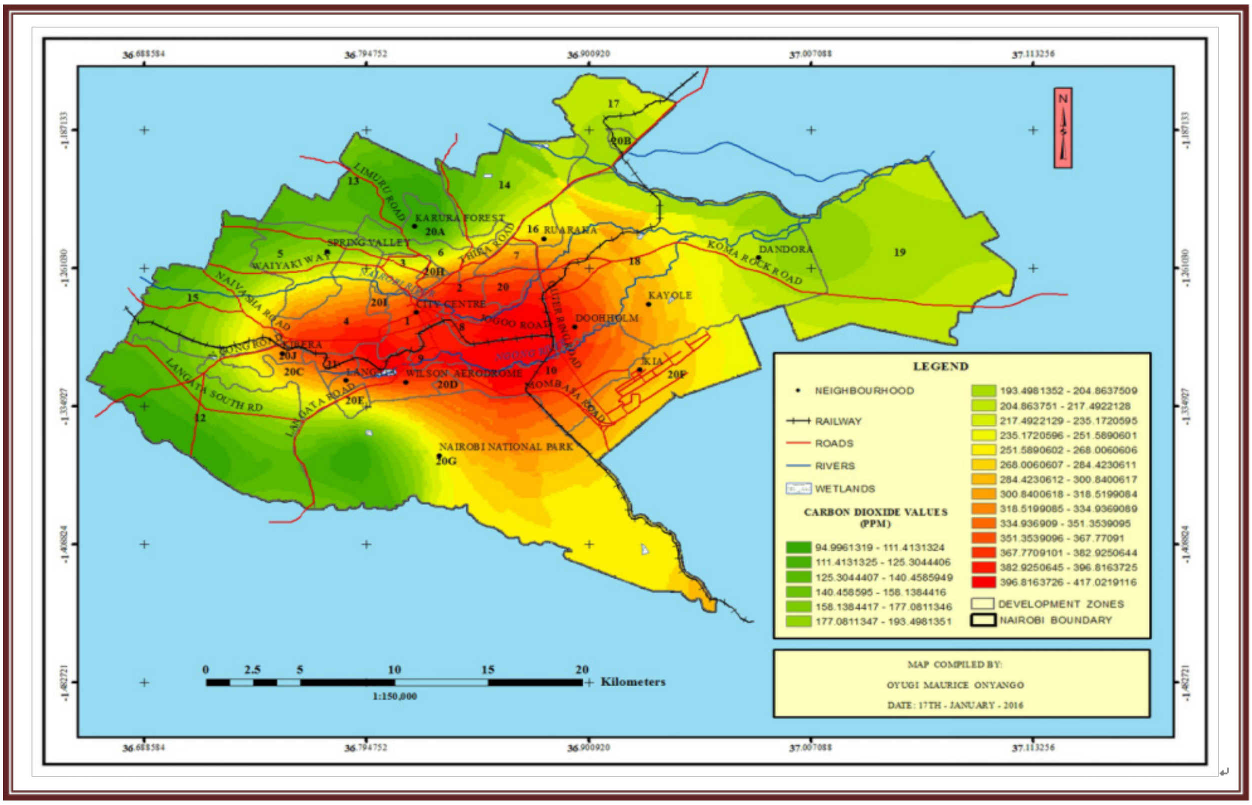

Figure 7. The Distribution of Carbon Dioxide Concentration Values in the City

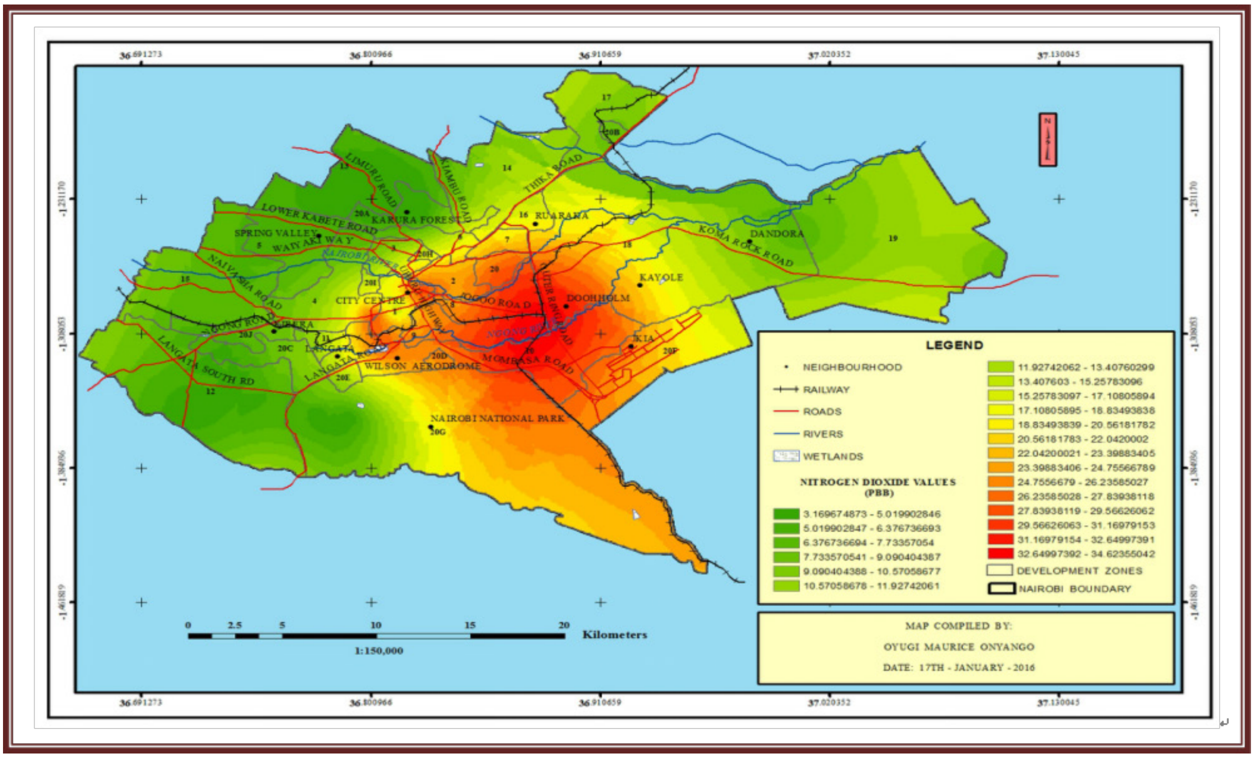

Figure 8. The Spatial Distribution of Nitrogen Dioxide Concentration Values in the City

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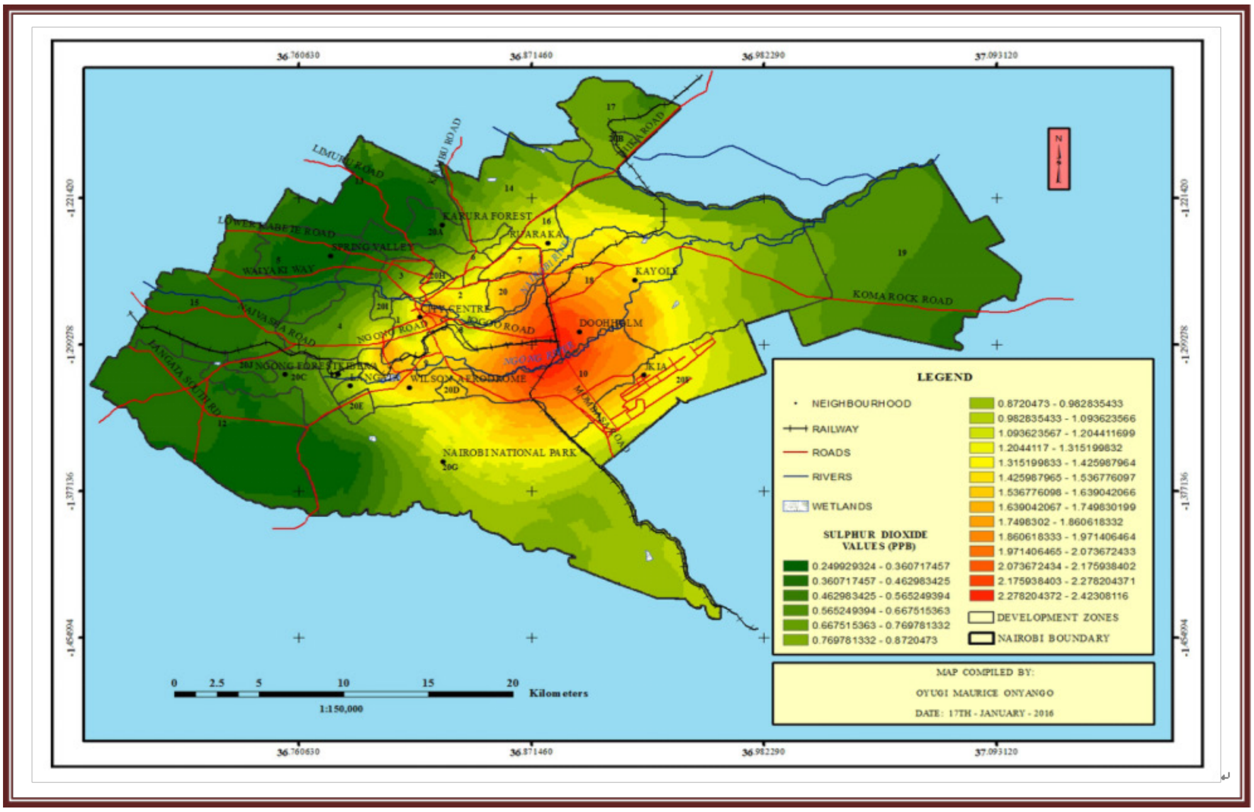

Figure 9. The Distribution of Sulphur Dioxide Concentration Values in the City

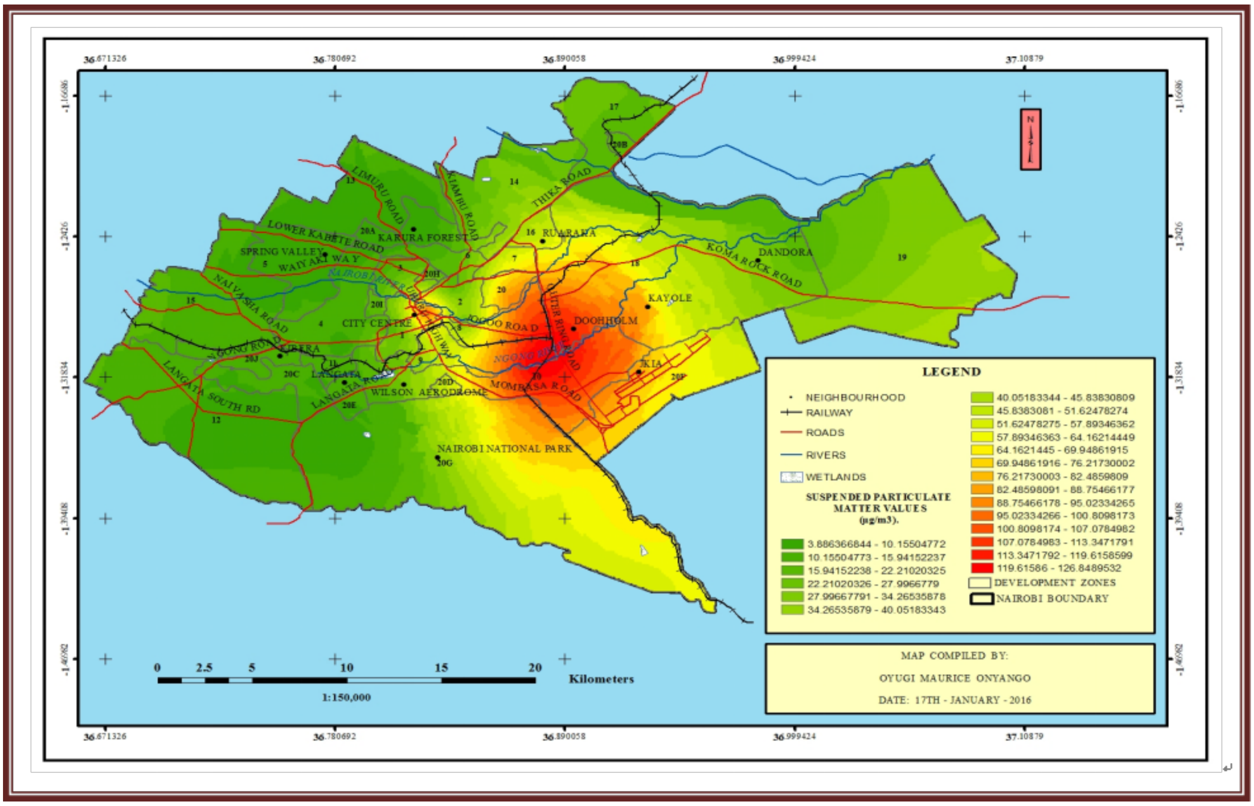

Figure 10. The Distribution of the Suspended Particulate Matter Concentration Values

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The Relationship between Urban Air Quality and Morphological Parameters

Urban morphological parameters of development density, land use and biomass index were utilised in establishing the relationship existing between urban morphology and air quality (Table 12). Results of the *Pearson's Product Moment Correlation Coefficient Indexes* of the relationships existing between and among the various morphological variables and air quality is also presented (Table 13). As earlier stated, the study was informed by the hypothesis that there exist significant relationships among the urban morphological variables under consideration as well as between the urban morphological variables and air quality. To demonstrate the intra-linkages existing between the morphological parameters, analysis of the relationship existing between

Table 12. The Morphological and Air Quality Attributes of the Development Zones

Development Zones	Air Quality Nominal Values (Y)	Urban Form Nominal Values		Biomass Index Nominal Values (VDNV) (X_3)	Urban Morphology Nominal Values (DDNV+LUNV +VDNV)	Average Urban Morphology Nominal Values (DDNV+LUNV +VDNV)/3
		Development Density Nominal Values (DDNV) (X_1)	Land Use Nominal Values (LUNV) (X_2)			
1	4.42	4.5	3.91	3.20	11.61	3.87
2	4.25	5.5	3.39	2.95	11.84	3.95
3	6.92	5.5	2.94	3.69	12.14	4.05
4	7.00	7.5	2.94	5.14	15.58	5.19
5	9.00	8.0	3.52	5.13	16.65	5.55
6	7.33	8.5	4.34	6.31	19.15	6.38
7	4.50	4.5	3.19	1.86	9.55	3.18
8	2.33	4.5	2.82	1.81	9.13	3.04
9	2.50	3.5	2.23	1.47	7.20	2.40
10	3.00	6.0	3.73	2.79	12.51	4.17
11	6.33	7.0	4.99	4.28	16.27	5.42
12	9.25	8.5	3.78	5.29	17.57	5.86
13	9.58	9.0	4.22	5.57	18.78	6.26
14	7.67	9.0	4.70	5.26	18.96	6.32
15	8.83	9.0	5.15	5.13	19.27	6.42
16	5.58	5.0	2.92	2.00	9.92	3.31
17	7.67	8.0	4.70	3.56	16.26	5.42
18	5.75	8.0	4.41	3.11	15.53	5.18
19	7.67	9.0	5.47	4.14	18.60	6.20
20	3.00	5.0	3.52	2.77	11.29	3.76
20A	9.00	9.5	7.52	8.21	25.21	8.40
20B	7.92	6.5	4.60	3.54	14.64	4.88
20C	8.25	9.5	7.60	8.03	25.12	8.38
20D	3.92	5.5	3.83	2.72	12.04	4.01
20E	7.08	9.5	6.86	6.55	22.91	7.64
20F	4.75	8.0	5.77	3.83	17.60	5.87
20G	6.00	10.0	7.81	7.82	25.63	8.54
20H	6.25	8.5	5.34	6.10	19.94	6.65
20I	6.25	7.5	4.98	5.46	17.94	5.98
20J	7.92	10.0	8.89	8.98	27.87	9.29

 DOI: https://doi.org/10.30564/jees.v3i2.3289

the development density and land use was undertaken. While the first analysis focused on the relationship with land use as the dependent variable, the second analysis focused on the relationship with development density as the dependent variable. In both the cases, the relationship existing between the two variables was established to be strong with correlation coefficient (r) values of -0.788 while the calculated *t*-values and critical *t*-values are 6.767 and 2.048 respectively. However, there is a slight difference in the calculated F-values for the two relationships as occasioned by differences in the regression models expressing the relationships. For the relationship in which the development density is the independent variable, the calculated F-value was established to be 45.798 compared to a critical F-value of 4.20. This had a slight difference from the relationship in which land use was the independent variable in which the calculated F-value was established to be 45.793 compared to a critical F-value of 4.20. This confirms that the relationship existing between the two variables is consistently significant (Table 14).

As corroborated by a correlation coefficient (r) value of -0.871, calculated and critical *t*-values of 9.392 and 2.048 respectively, with a corresponding calculated F-value of 88.216 compared to a critical F-value of 4.20, the relationship existing between development density and biomass index is confirmed to be very significant and consistent. Similarly, a correlation coefficient (r) value of 0.840, a calculated *t*-value of 8.185 compared to the critical *t*-value of 2.048, corresponding to a calculated F-value of 66.992 compared to a critical F-value of 4.20, the relationship existing between land use and the biomass index is confirmed to be very significant and consistent.

Table 13. Correlation Matrix Variables

Variables	Air Quality	Development Density	Land Uses	Biomass Index
Air Quality	1.000	-0.775	0.446	0.684
Development Density	-0.775	1.000	-0.788	-0.871
Land Uses	0.446	-0.788	1.000	0.840
Biomass Index	0.684	-0.871	0.840	1.000

There is a strong negative relationship existing between development density and air quality. This is corroborated by a correlation coefficient (r) value of -0.7751 and a calculated *t*-value of 6.492 compared to a critical *t*-value of 2.048. While the calculated F-value for the relationship is 42.149, the critical F-value is 4.20. This confirms that the relationship existing between the two variables is not occurring by chance. Contrary to the above, land uses and air quality present a weak relationship evidenced by a correlation coefficient (r) value of 0.446 and a calculated *t*-value of 2.638 compared to a critical *t*-value of 2.048. The calculated and critical F-values for the relationship are 6.961 and 4.20 respectively. This is attributed to the transboundary nature of the air pollutants spreading through the wind, thus a neighbourhood surrounded by noxious land uses will still experience low air quality. Granted that the correlation coefficient (r) value for the relationship existing between the biomass index and air quality is 0.684, the study confirms that the relationship is moderately significant as corroborated by the calculated *t*-value of 4.956 compared to a critical *t*-value of 2.048. Since the calculated F-value of the relationship is 24.56 compared to a critical F-value of 4.20, the relationship existing between biomass index and air quality is significant and consistent.

The study further established a consistently moderate relationship existing between urban form (aggregation of development density and land use nominal values) and air quality. This is confirmed by a correlation coefficient (r) value of 0.657, a calculated *t*-value of 4.614, a calculated F-value of 21.291 with a corresponding critical F-value of 4.20. The study also established a moderately significant correlation existing between urban morphology (aggregation of development density, land use and biomass index nominal values) and air quality as evidenced by a correlation coefficient (r) value of 0.682. While the significance of the relationship is confirmed by a calculated *t*-value of 4.937 compared to a critical *t*-value of 2.048, the consistency of the relationship is confirmed by a calculated F-value of 24.373 compared to a critical F-value of 4.20. To facilitate the determination of the strengths of the relationships existing between morphological variables and air quality, regression models depicting the relationships were established. In addition to other statistical attributes, the relationship existing between urban form elements and air quality is represented by regression equation 9.

$$\acute{Y} = -0.490X_1 - 2.202X_2 + 50.015 \quad (9)$$

Where: -

$\acute{Y}$ = The estimated air quality values

X_1 = Development density values

X_2 = Land use nominal values

While the calculated *t*-value attributed to the development density in the model is 6.241, the calculated *t*-value attributed to land uses is 2.422, the calculated *t*-value attributed to error term is 7.944 and the calculated F-value is 27.670. This corroborates the significant role the development density plays in the determination of the spatial distribution of the air quality within the city as compared to land uses.

  DOI: https://doi.org/10.30564/jees.v3i2.3289

Table 14. Relationships Existing Between and among the Morphological Variables and Air Quality

Statistical Elements	Relationship Variables			
	Development Density and Air Quality	**Development Density and Land Use**	**Land Use and Air Quality**	**Biomass Index and Air Quality**
Correlation Coefficients	-0.7751	-0.788	0.446	0.684
Coefficients of Determination (r^2 or R)	0.6008	0.621	0.199	0.467
Calculated t - Value	6.492	6.767	2.638	4.956
Critical t - Value	2.048	2.048	2.048	2.048
Regression Model	**Y = -0.085X + 8.8316**	**Y = -0.068X + 6.6709**	**Ỳ = 0.567X + 3.682**	**Ỳ = 0.711X + 3.089**
ANOVA or the F- Test Value	42.149	45.798	6.961	24.56
Critical F - Value	4.20	4.20	4.20	4.20

	Relationship Variables		
	Development Density and Biomass Index	**Land Use and Development Density**	**Land Use and Biomass Index**
Correlation Coefficients	-0.871	-0.788	0.840
Coefficients of Determination (r^2 or R)	0.759	0.621	0.705
Calculated t-Value	9.392	6.767	8.185
Critical t - Value	2.048	2.048	2.048
Regression Model	**Y = -0.9193X + 72.639**	**Y = -9.1227X + 72.03**	**Y = 10.262X - 2.3316**
ANOVA or the F- Test	88.216	45.793	66.992
Critical F - Value	4.20	4.20	4.20

	Relationship Variables	
	Urban Form and Air Quality	**Urban Morphology and Air Quality**
Correlation Coefficients	0.657	0.682
Coefficients of Determination (r^2 or R)	0.432	0.465
Calculated t-Value	4.614	4.937
Critical t - Value	2.048	2.048
Regression Model	**Y = 1.6346X +5.6937**	**Y = 1.0857X + 7.3336**
ANOVA or the F- Test	21.291	24.373
Critical F - Value	4.20	4.20

The relationship existing between the urban morphological parameters of development density, land use, biomass index and air quality represented by model 10 reveals varying levels of significance.

$$\acute{Y} = -0.389X_1 - 3.060X_2 + 0.174X_3 + 43.123 \quad (10)$$

Where: -

Ý = The estimated air quality values

X_1 = Development density values

X_2 = Land use nominal values

X_3 = Biomass Index values

Other statistical parameters in the relationship are: -

t_1 = The calculated *t*-value attributed to development density which is 3.978

t_2 = The calculated *t*-value attributed to land uses which is 2.654

t_3 = The calculated *t*-value attributed to biomass index which is 2.992

t_4 = The calculated *t*-value attributed to error term which is 5.835

F = Calculated F-value of the relationship which is 20.544

It is therefore evident that development density is the most significant determinant of air quality distribution in the city, followed by biomass index and land uses. Since the calculated *t*– value attributed to error term in the model is significant, it implies that there are some variables which were not considered in the study but are determinants of the spatial distribution of the air quality in the city.

4. Conclusions and Recommendations

The study, which finds impetus on the effects of urbanisation on global warming and climate change, provides a niche for the development of a unifying model explaining the correlation existing between urbanisation, urban morphology, air quality, global warming and climate change. Indeed, the study establishes that the most significant urban morphological variable influencing the spatial distribution of air quality is development density followed by biomass index and to a weaker extent, land uses. This is because urban developments deplete vegetation cover leading to increased impervious surfaces such as buildings and roads, consequently lowering the purification ability of the ecosystem. Further, increased development leads to urban sprawl, which increases vehicular volume to exacerbate GHGs, suspended particulate matter and sulphur dioxide emissions. This makes cities a major contributor to global warming and climate change. High development densities also influence urban air quality through attenuation of wind velocity, restricting air pollutants in the narrow canyons, leading to the concentrations of the same. Through a combination of shading, evaporative cooling effects and photosynthetic processes, vegetation mitigates urban neighbourhoods against air pollution and heating effects generated by the developments. This makes development density and biomass index imperative morphological parameters determining the distribution of urban air quality.

The study further establishes that the air quality distribution in the city can broadly be dichotomised into four broader categories namely; the northern and western, southern, eastern and the central parts of the city, which significantly corresponds to the development density, industrial and transportation networks as well as vegetation distribution. Since red volcanic soils, which characterises the northern and western parts of the city, are rich in nutrients and humus contents, they support healthy natural and exotic vegetation, which are carbon sinks and purifier to other GHGs. The southern and eastern parts of the city which are characterised by low-lying plains and black cotton soils with low nutrient contents are dominated by sparse vegetation covers such as the disturbed bushes, shrubs, perennial grasses and under storey trees which are not effective purifier of gases. Therefore, the presence of forest reserves to the northern and western parts of the city coupled with low development densities characterising the regions have acted in concert towards the achievement of relatively better air quality. This contrasts with the central, southern and eastern parts of the city, which are characterised by sparse vegetation covers, high development densities and dominance of land uses such as transportation, industrial developments and quarries, which compromises the air quality. Therefore, the study concludes that development density has acted in concert with biomass index, physiographical, climatological and pedological factors to influence the distribution of the air quality within Nairobi city.

5. Recommendations

The achievement of sustainable urban air quality requires implementation of multiple strategies and techniques, which are known to work within the standard practice of urban environmental planning and management. Such strategies include promotion of green infrastructure, implementation of appropriate development densities, tightening up legislations on protection of urban ecosystems such as the green belts, gardens, trees and implementation of sustainable industrial and transportation networks. Urban environmental management further requires a new environmental contract encompassing civil society, public and private sector participations. This should build on the strengths of planning and other environmental management strategies, which give

DOI: https://doi.org/10.30564/jees.v3i2.3289

encouragement to local and regional institutional capacity building, behavioural change and innovation. For the achievement of sustainable air quality in Nairobi city, the study recommends the following:

(1) Enhancement of Vegetation Cover within the City

The vegetation cover enhances air quality, however this is negated by the urban sprawl characterising the eastern and southern parts of the city. Therefore, to achieve sustainable air quality, measures such as the implementation of appropriate development policies geared towards increasing the vegetation cover should be prioritised. Such policies should entail tightening up legislations protecting urban ecosystems, minimisation of land fragmentations and urban sprawl through up-scaling sky lines, increments of plot coverages, ratios and minimum plot sizes for developments as well as strict enforcement of density standards inclusive of spelt out number of trees to be planted per acreage of plot. In accordance with the provisions of Environmental Impact Assessment Regulations of 2003, all the proposed developments within the city that are likely to compromise the air quality should be subjected to Environmental Impact Assessment.

(2) Expansion and Regular Maintenance of the Urban Infrastructure

Increased frequencies of sewer blockages and bursts indicate that developments in the city have surpassed the capacity of the existing infrastructure. Therefore, for the city to continue supporting the growing population through re-densification which control urban sprawl, there is need for expansion and regular maintenance of the existing water reticulation, sewer and road networks.

(3) Enhancement of Air Quality through Creation of Monitoring Stations and Enactment of Appropriate Transportation and Industrial Development Policies

Industries and motor vehicles emits GHGs, sulphur dioxide and suspended particulate matter, which apart from lowering the urban air quality also makes cities major contributors of global warming and climate change. Therefore, the Nairobi City County Government should formulate policies, standards and legislations for the reduction of air pollution in the city. The policies should include popularisation of public transportation, non-motorised modes of transportation, limiting the number of vehicles coming into the city and development of arterials which supports rapid vehicular flow for it has been established that vehicles emit more GHGs, sulphur dioxide and suspended particulate matter when their speeds are low. The focus should further be placed on industrial and commercial districts characterised by vehicular concentration and high density developments, which apart from depleting the vegetation cover also restricts the dispersal of air pollutants, leading to increased concentrations of the same. Policy measures such as decentralisation of industrial and commercial districts should be pursued. For this to be implemented, there is need for frequent air quality monitoring which can be achieved through establishment of network of stationary air quality monitoring stations and frequent mobile air quality monitoring along road transects.

(4) Instituting Geospatial, Information and Communication Technologies (GICTs) in Urban Planning and Growth Management in line with the Recommendations of Sustainable Development Goals (SDGs)

In undertaking reviews of development plans geared towards the development of compact city, cognisance should be taken of land use suitability. This is impetrative in protecting the fragile ecologies notably the forests and riparian reserves against the encroachment by anthropogenic activities which in turn exacerbates flood disasters, leading to loss of life and property. However, the above can effectively be undertaken if the County Government institute the utility of ICT and geospatial techniques as planning tools which is in line with the SDGs' stipulations.

(5) Multi-Sector Partnership Approach to Air Quality Management

Despite the constitutional stipulations on the involvement of the citizens in the development plan formulation and implementation, current urban development paradigms operational in the city are not participatory and various development agents feel left out in the process. Therefore, in the evolution and review of development plans, the people and various development agents should be brought on board. This makes it easy for development agents to understand issues entailed in the plan and to take charge in implementing the same. This requires enactment of policy framework on partnership building as well as registering neighbourhood associations and empowering the same to undertake self-driven development control and air quality compliance monitoring.

DOI: https://doi.org/10.30564/jees.v3i2.3289

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DOI: https://doi.org/10.30564/jees.v3i2.3289

APPENDIX

DEVELOPMENT ZONES OF NAIROBI

Zone	Areas Covered	Zone	Areas Covered
1	Central Business District (CBD/Upper Hill Area	2	Eastleigh Pumwani/California Ziwani/Starehe
3	Westlands Parklands' City Park Estate/Upper Parklands	4	Spring Valley Riverside Drive Kileleshwa Kilimani Thompson Woodley
5	Upper Spring Valley Kyuna Loresho Lavington/Bernard Estate		
6	Muthaiga New Muthaiga	7	Mathare/Mathare North/Lower Huruma Kariobangi/Korogocho Dandora
8	**Old Eastlands** Shauri Moyo/Maringo/Bahati Kaloleni/Makongeni Mbotela/Jericho/Jerusalem Kariobangi Lt/Industrial Mathare North Lt/Industrial Kariobangi Lt/Industrial	9	**Industrial Area** Nairobi West/Madaraka South 'B'/South 'C' Nairobi Dam/Ngummo Highview/Magiwa Golf Course/Langata Estates
10	Southlands Otiende/Ngei 1&2 Onyonka/Masai Jonathan Ngeno/Villa Franca Imara Daima/Tassia Fedha/Avenue/Embakasi Village	11	**Special Scheduled Area (Kibera Slums)** **National Housing Corporation (NHC) Estates** • Ayany • Olympic • Fort Jesus • Karanja Road
12	Karen/Langata	13	Gigiri/Kitisuru/Ridgeways Garden Estate Safari Park/Balozi Housing
14	Roysambu Thome Marurui	15	Dagoretti • Riruta • Kangemi • Mutuini • Waithaka • Ruthimitu • Uthiru
16	Baba Dogo Ngumba/Ruaraka	17	Githurai 44&45 Zimmerman Kahawa West
18	**Kasarani** • Clayworks • Clay City • Sports View • Mwiki • Njiru • Ruai	19	**Special Scheduled Area** • Githurai Kimbo • Wendani • Kahawa Sukari

Zone	Areas Covered		Zone	Areas Covered
20	**Public/Strategic Reserved Areas (Gazetted)** • State House • JKIA Airport • Wilson Airport • Military Sites o Military Airbase Eastleigh o DoD Headquarters o Kahawa Barracks o Langata Barracks o Defence College, Karen o Forces Memorial Hospital		20g	**Recreational and Forests** • City Park • Arboretum • Ngong Forest • Karura Forest **National Game Park** **Stadia** • Moi Sports Complex, Kasarani • City Stadium • Nyayo Stadium Uhuru Park Central Park Uhuru Park Central Park Uhuru Gardens

DOI: https://doi.org/10.30564/jees.v3i2.3289

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Journal of Environmental & Earth Sciences
https://ojs.bilpublishing.com/index.php/jees

ARTICLE

Assessment of Rainwater and Groundwater Quality in Izombe Town, Oguta Local Government Area of Imo State

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ARTICLE INFO

Article history
Received: 16 August 2021
Accepted: 16 September 2021
Published Online: 28 September 2021

Keywords:
Assessment
Rainwater
Groundwater
Coliform
Izombe

ABSTRACT

Rainwater and groundwater quality in Izombe were assessed. Five water samples were collected from five (5) different locations, with at least one location from one of the four autonomous communities in Izombe, Oguta L.G.A of Imo State. The physicochemical and microbial parameters of rainwater and groundwater samples from Umuakpa, Ndeuloukwu, Ugbele, Ndioko, and Orsu were assessed using Varian Atomic Absorption Spectrophotometer (AAS). The study was aimed to assess the physicochemical and microbial qualities of groundwater and rainwater in Izombe and how these affect their health as individual members of the community, and their environment when compared to WHO standards. The water samples were collected from five different locations, with at least one location from each of the four autonomous communities, and were assessed. The result indicated that rainwater and groundwater pollutants in the community were turbidities, ammonia, copper and temperatures 7.59±0.02 ph, 6.42±0.28 nitrate, 59.56±0.50 ammonia, 0.29±0.07 phosphate, 0.88±0.03 iron, copper, lead, nickel, aluminum, mercury, manganese, cadmium, bacteria count, coliform count, and E-coli. Also, all the pollutant parameters were identified, only iron, copper, aluminum, and bacteria count were not identified as being associated with petroleum products and exploratory activities. This research has broadened the understanding of the suitability of Izombe water sources for both consumption and other purposes. The findings show that the rain and groundwater sources of the community are not fit for human consumption, due to the contaminants inherent in them, attributed majorly to the oil production activities in the area which corroborates other research studies.

1. Introduction

Water is an essential natural resource for the sustainability of life on earth [1,2]; described water as a compound of two molecules, Hydrogen, and Oxygen that exists naturally in forms of ground and rainwater. Water is one of the unique molecules known to man [3], also one of the most important to biological systems. Glen further states that water is the only common pure substance that exists naturally in all three states of matter (solid, liquid, gas). It also covers 75 percent of the earth and composes roughly 78 percent of the human body. Water is the most abundant molecule on Earth's surface, composing 70-75% of the Earth's surface as a liquid and solid-state in addition

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 DOI: https://doi.org/10.30564/jees.v3i2.3582

to being found in the atmosphere as a vapor.

Izombe community is one of the oil-producing areas in the Niger Delta region of Nigeria. However, before the discovery of crude oil in the area, the people of Izombe traditionally as a sub-Sahara African community was of an agrarian economy, which covers farming, palm wine tapping, and fishing, with a very small industrial sector. Even with the discovery of crude oil, the people of Izombe still depend on their land and water for their agrarian economy. The income of most common people in the area comes from staple food and palm produce. Agriculture provides about 60% of the employment and more than 70% of the total economic exchange earnings. About 90% of their food supplies and consumption is locally produced.

Just like any other agrarian community, it is obvious that the people of Izombe depend greatly on the quality of rainwater and groundwater for their economic development. The availability and quality of water (rain or ground) do not only control the level of agrarian productivity but also determine the level of good health enjoyed by the people of any environment. Researches and surveys have however shown that geographical location, human activities as well as industrial emissions, contribute very largely to the variability in quality and availability of rain and groundwater. These factors are therefore of great importance to the physical, economic and environmental development of Izombe.

A state that recognized that environmental factors can affect health in its broadest sense [4], it is often difficult to isolate and quantify the risk that might arise from these exposures because of their close interactions with other health determinants'. One of the other health determinants that [4] made efforts to identify is 'Water'. It is a major health determinant, which interacts with other exposures to influence that state of human and environmental health. Its positive or negative influence on health, therefore, depends on the quality of the water. This position is in agreement with the [5] which attributes an estimate of 24% of the global disease burden to environmental factors, whilst in the United Kingdom, the estimate is about 14%. Unfortunately, the understanding of the complex and multi-faceted relationships that exist between exposures to environmental and health risks is limited.

Some scholars like [6,7], have come to a common opinion that water as rain, acquires its salinity and bacteriological composition partly as it passes through the atmosphere by dissolving air-borne particulates from natural or industrial activities and water-soluble gases, as well as absorbing air-borne microbes. Its quality may further degrade as it infiltrates into the soil, causing leaching and weathering of the geological medium, which results in the dissolution or precipitation of some mineral constituents and human chemical deposits in the soil, which add to groundwater contamination.

It was observed that previous studies on the quality of water resources in the tropical African environment have largely been restricted to surface and groundwater to the negligence of rainwater [8]. Also it was opined that this negligence is predicated upon the assumption that rainwater is usually very pure and therefore needs very little investigation [8].

The vulnerability therefore of rainwater and groundwater to quality degradation from human activities makes a periodic assessment of their qualities necessary. In consideration of the above facts, the researcher desires to assess the quality of rain and groundwater in Izombe. This is necessary not just because water quality controls the level of healthy living of the people, but also with the consciousness that the area is an agrarian environment, where the level of agricultural productivity depends on rain and groundwater qualities. The impetus for this study on rain and groundwater quality assessment is also driven by the additional fact that Izombe is an oil-producing community, with the assumptions that chemical emissions and spillages from the oil production activities have possibilities of impairing water qualities in the area.

In this study, therefore, the researcher seeks to asses, analyze and determine the quality of rain and groundwater in Izombe community of Oguta Local Government Area of Imo State. To achieve this purpose, this study considers the various factors contributing to the quality of rain and groundwater, with a special focus on oil-producing communities. The study also focuses on environmental and health implications of the water quality and the various negative impacts of agricultural and oil production activities on water quality in Izombe as an agrarian and oil-producing community.

2. Materials and Methods

2.1 Description of Study Area

Izombe autonomous community is one of the

DOI: https://doi.org/10.30564/jees.v3i2.3582

communities in the Oguta Local Government Area of Imo State. The community is located on the western geographical axis of Imo State. Imo State is one of the 36 states of the Federal Republic of Nigeria, with Owerri as the capital and the largest city. The state was created on February 3, 1976, from the old East Central State. The state lies between latitude 4.45° N and 7.15° N and longitude 6.50°E and 7.25° E. It occupies the Lower Niger Basin and Upper Imo River. The state shares borders in the East with Abia State, in the West with River Niger and Delta state, in the North with Anambra State, while Rivers State is in the South. Imo state has a population of about 4.8million persons. Imo State which covers approximately a land area of 12,689 square kilometers, has (27) twenty-seven local government areas, of which Oguta local government is one. The density population of the Oguta local government area where Izombe community belongs is about 230 persons per square kilometer.

Izombe is one of the oil-producing communities in the Niger Delta region of Nigeria. Before the discovery of crude oil in the area, the people of Izombe traditionally a sub-Sahara African community is of an agrarian economy, which covers farming, Palm oil production, palm wine tapping, and fishing, with a very small industrial sector. It is not farfetched therefore why the researcher considered Izombe as the best area for this study. The activities of oil companies and other allied industries make the area prone to daily pollution from hydrocarbons and other industrial chemical and solid pollutants. Above all, the community depends daily on the water for their daily living and economic activities. The quality of water, therefore, is a primary factor in Izombe as an oil-producing community.

2.2 Sample Collection

Five (5) water samples were obtained from five (5) different places, with at least one sample collected from one of the four autonomous communities in Izombe (see Tables 1 and 2). Twenty villages were divided into four autonomous groups based on their geographical distribution, and 20 samples were taken from each group. The locations from which the samples were taken are given in Table 1. Distance from the borehole to a potential source of contamination was measured with a standard meter rule and recorded. The determination of dissolved oxygen and temperature were measured using DO_2 meter. The groundwater samples from the 5 distinct boreholes were labeled GW1–GW5, while the rainfall samples were called RW1–RW5 samples for convenience. In August of 2017, groundwater samples were obtained in the early morning hours when newly pumped from the ground, following the Nigerian Standard for Drinking Water Quality (NSDQW) standard practices for Water Quality Analysis, and rainwater was collected directly from the cloud into a sterile wide-mouthed basin that was put on top of an empty large drum, avoiding splashes of sand and other debris from the land. All bottles (Teflon beaker) were used for sample collection and disinfected, cleaned, and rinsed with distilled water before collection as part of quality control protocols. Before the final water sampling, the bottles were rinsed three times with the sample water at the place of collection. To avoid contamination of the water by the hands or fingers, the bottles were held at the bottom while being filled [9]. All of the sample containers were maintained in iceboxes until they were transported to the lab for analysis. Also, the determination of heavy metals using atomic absorption spectrophotometer (AAS) was carried out using FS 240 varian atomic absorption spectrophotometer, acetylene gas, and air oxidant gas etc with 1000 ppm AI standard solution.

2.3 Tests for Physicochemical and Microbiological Parameters

The following microbiological parameters were tested on the samples taken from the various units: Biochemical Oxygen Demand (BOD), Total Viable Count (TVC), and coliform test. The analysis was carried out using a membrane filter (MF) and a pour plate technique. According to the processes specified, the chemical parameters were: hardness, sulfate (SO_4^{2-}), nitrate (NO^{3-}), calcium (Ca^{2+}), zinc (Zn), manganese (Mn), lead (Pb), iron (Fe), magnesium (Mg), alkalinity ($CaCO_3$), ammonia (NH_3), and pH. Taste, odor, and temperature were determined by physically inspecting the samples. The concentration of suspended and dissolved solids, which yielded the total dissolved solids of the individual samples, was also evaluated [10].

3. Results

Table 1. Groundwater physicochemical and microbial parameters from the five (5) communities in Izombe

PARAMETERS	UMUAKPA	NDEULOUKWU	UGBELE	NDIOKO	ORSU	Mean ±SD	WHO STD
Temperature °C	28.03±0.06^{a}	28.13±0.15^{a}	27.93±0.16^{a}	27.77±0.15	28.60±0.01	28.09±0.15	20-30
Conductivity (µs/cm)	13.33±0.57^{b}	30.18±0.15^{b}	37.90±0.14^{b}	32.67±0.58^{a}	15.00±1.00^{a}	25.82±0.14	100
Colour (PCU)	4.33±1.15^{c}	59.27±0.23^{c}	25.85±0.13^{c}	13.68±0.58^{b}	16.33±0.58^{b}	23.89±0.25	15.00
Turbidity (NTU)	1.72±0.02^{d}	24.82±0.08^{d}	0.00±0.00^{d}	5.63±0.01	5.80±0.02	7.59±0.02	5.00
Ph	5.57±0.12^{e}	6.90±0.15^{e}	5.53±0.26^{e}	6.73±0.06	7.37±0.15	6.42±0.28	6.5-8.5
Dissolved Oxygen (mg/l)	7.83±0.11	6.89±0.10^{f}	7.95±0.08	5.13±0.15	6.87±0.06	6.93±0.09	>4
Total dissolved solids (mg/l)	9.10±0.10f	19.54±0.06^{g}	24.66±0.03^{f}	20.77±0.06^{c}	9.73±0.02^{c}	16.76±0.04	250
Total suspended solids (mg/l)	1.07±0.12g	14.19±0.17^{h}	4.21±0.21^{g}	2.93±0.12^{d}	3.33±0.58^{d}	5.14±0.15	50
Chlorine (mg/l)	0.02±0.01	0.25±0.03	0.11±0.01	0.25±0.01	0.17±0.02	0.16±0.02	0.2-0.25
Nitrate (mg/l)	121.33±0.25^{h}	31.26±0.22^{i}	87.33±0.07^{h}	25.20±0.10	32.67±0.58	59.56±0.50	40.00
Nitrate-Nitrogen (mg/l)	27.47±0.15^{i}	9.43±0.04^{j}	19.63±0.07^{i}	5.70±0.10	7.20±0.20	13.89±0.3	15.00
Ammonia (mg/l)	0.26±0.02	0.42±0.11	0.38±0.03	0.30±0.01	0.12±0.02	0.29±0.07	0.30
Phosphate (mg/l)	1.13±0.15	1.22±0.03^{k}	0.52±0.03	0.43±0.06^{e}	1.10±0.17	0.88±0.03	5.0
Phosphorus (mg/l)	0.33±0.15	0.44±0.05	0.12±0.03	0.20±0.02	0.32±0.03	0.28±0.02	0.3
Sulphate (mg/l)	5.17±0.15^{j}	5.21±0.21^{L}	5.00±0.02^{j}	5.13±0.15^{f}	5.13±0.15^{e}	5.13±0.15	100
Zinc (mg/l)	0.00±0.00	0.02±0.00	0.03±0.00	0.03±0.00	0.00±0.00	0.02±0.01	5.0
Alkalinity (mg/l) $CaCO_3$	19.67±0.58^{k}	5.21±0.21^{m}	60.00±0.03^{k}	4.67±0.58^{g}	50.03±0.06^{f}	27.92±0.03	200
Chromium (mg/l)	0.00±0.00	0.02±0.00	0.00±0.00	0.01±0.00	0.01±0.01	0.01±0.00	0.05
Calcium (mg/l)	0.22±0.02	0.12±0.02	0.19±0.02^{L}	0.12±0.02	0.18±0.02	0.17±0.02	150
Magnesium (mg/l)	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.01±0.01	0.002±0.01	150
Iron (mg/l)	0.90±0.01	0.53±0.02	0.03±0.01^{m}	0.13±0.01	0.06±0.01	0.33±0.01	0.3
Copper (mg/l)	0.92±0.02	2.72±0.09^{n}	0.13±0.01	7.45±0.02^{h}	0.64±0.02	2.37±0.03	1.0
Lead (mg/l)	0.87±0.02	0.29±0.02	0.78±0.03	0.21±0.01	0.36±0.02	0.50±0.01	0.05
Nickel (mg/l)	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.02
Aluminium (mg/l)	1.61±0.01	1.93±0.05	1.33±0.03	1.75±0.01	1.62±0.02	1.65±0.02	0.20
Mercury (mg/l)	2.30±0.10^{L}	2.54±0.15	5.02±0.06	0.70±0.01^{i}	1.21±0.02^{g}	2.35±0.04	0.002
Manganese (mg/l)	0.22±0.01	0.08±0.00	0.31±0.02	0.33±0.00	0.14±0.00	0.22±0.01	0.2
Cadmium (mg/l)	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.005
BOD (mg/l)	9.17±0.15^{m}	2.53±0.38^{o}	10.51±0.31^{n}	1.11±0.01	1.30±0.01	4.92±0.01	30
Bacterial count (CFU/100ml)	53.00±1.00^{n}	12.00±1.00^{p}	57.33±0.58^{o}	6.67±0.58^{j}	8.67±0.58	27.53±0.58	5-10
Coliform count (cfu/100ml)	31.33±1.52^{o}	2.33±0.58^{q}	34.00±0.00^{p}	3.00±1.00^{k}	4.33±0.58	14.99±0.24	10
E.coli (cfu/100ml)	10.67±0.58^{p}	2.33±0.58^{r}	11.00±0.00^{q}	6.67±0.58	4.00±1.00	6.93±0.29	0

 DOI: https://doi.org/10.30564/jees.v3i2.3582

Table 2. Rainwater physicochemical and microbiological parameters from the five (5) communities in Izombe

PARAMETERS	UMUAKPA	NDEULOUKWU	UGBELE	NDIOKO	ORSU	Mean±SD	WHO STD
Temperature ^{o}C	25.73±0.15^{a}	29.33±0.05^{a}	29.13±0.06^{a}	27.77±0.15	27.73±0.15	27.94±0.13	20-30
Conductivity (µs/cm)	5.33±0.57^{b}	0.50±0.00^{b}	12.00±1.00^{b}	8.33±1.32^{a}	42.67±0.58^{a}	13.77±0.12	100
Colour (PCU)	37.00±1.00^{c}	1.00±0.00^{c}	2.67±0.58^{c}	26.33±7.23^{b}	35.33±2.08^{b}	20.47±0.35	15.00
Turbidity (NTU)	6.47±0.01^{d}	4.52±0.01^{d}	2.73±0.12^{d}	6.83±0.06	6.24±0.03	5.36±0.03	5.00
Ph	7.57±0.15^{e}	4.80±0.01^{e}	7.12±0.15^{e}	7.25±0.15	7.25±0.15	6.80±0.16	6.5-8.5
Dissolved Oxygen (mg/l)	6.70±0.10	8.07±0.06^{f}	7.63±0.12	8.63±0.25	7.57±0.15	7.72±0.9	>4
Total dissolved solids (mg/l)	3.27±0.03^{f}	3.25±0.01^{g}	7.67±0.15^{f}	4.37±0.15^{c}	7.87±0.09^{c}	5.29±0.03	250
Total suspended solids (mg/l)	6.33±0.58^{g}	0.00±0.00^{h}	0.00±0.00^{g}	10.00±0.00^{d}	7.33±0.58^{d}	4.73±0.21	50
Chlorine (mg/l)	0.14±0.01	0.05±0.01	0.04±0.01	0.05±0.01	0.09±0.01	0.07±0.01	0.2-0.25
Nitrate (mg/l)	63.73±0.15^{h}	63.42±0.01^{i}	60.26±0.02^{h}	27.87±0.15	33.80±0.10	49.82±032	40.00
Nitrate-Nitrogen (mg/l)	14.27±0.15^{i}	14.43±0.02^{j}	13.67±0.02^{i}	6.10±0.17	7.63±0.15	11.22±0.10	15.00
Ammonia (mg/l)	0.22±0.01	0.46±0.01	0.65±0.01	1.57±0.02	1.51±0.01	0.88±0.03	0.30
Phosphate (mg/l)	0.60±0.20	0.50±0.10^{k}	1.38±0.02	11.60±0.20^{e}	0.37±0.06	2.89±0.04	5.0
Phosphorus (mg/l)	0.21±0.01	0.26±0.20	0.40±0.02	3.73±0.11	0.23±0.06	0.97±0.02	0.3
Sulphate (mg/l)	22.00±2.00^{j}	10.00±0.00^{L}	10.00±0.00^{j}	16.00±1.00^{f}	10.67±0.58^{e}	13.73±0.08	100
Zinc (mg/l)	0.00±0.00	0.65±0.00	0.47±0.01	0.35±0.00	0.22±0.00	0.34±0.01	5.0
Alkalinity (mg/l) $CaCO_3$	54.33±1.15^{k}	59.67±0.58^{m}	31.33±1.52^{k}	44.67±1.52^{g}	63.33±5.77^{f}	50.67±0.06	200
Chromium (mg/l)	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.01±0.00	0.05
Calcium (mg/l)	0.17±0.01	2.14±0.01	1.26±0.02^{L}	0.86±0.01	1.04±0.01	1.09±0.02	150
Magnesium (mg/l)	0.00±0.00	0.04±0.01	0.03±0.01	0.03±0.01	0.05±0.01	0.03±0.01	150
Iron (mg/l)	0.00±0.00	0.09±0.01	90.05±0.01^{m}	1.25±0.01	1.10±0.02	9.05±0.01	0.3
Copper (mg/l)	0.05±0.03	0.02±0.01^{n}	0.23±0.12	0.01±0.01^{h}	0.08±0.01	0.08±0.02	1.0
Lead (mg/l)	0.00±0.00	0.87±0.06	0.04±0.02	0.23±0.01	0.83±0.01	0.39±0.01	0.05
Nickel (mg/l)	0.08±0.00	0.00±0.00	0.00±0.00	0.35±0.00	0.40±0.01	0.17±0.02	0.02
Aluminium (mg/l)	1.17±0.02	2.33±0.58	1.67±0.06	1.16±0.01	1.25±0.01	1.52±0.03	0.20
Mercury (mg/l)	0.21±0.02^{L}	2.57±0.15	3.13±0.12	3.33±0.11^{i}	3.97±0.15^{g}	2.64±0.01	0.002
Manganese (mg/l)	0.00±0.00	0.04±0.01	0.70±0.10	0.55±0.02	0.43±0.02	0.34±0.02	0.2
Cadmium (mg/l)	0.00±0.00	0.00±0.00	0.02±0.00	0.01±0.00	0.00±0.00	0.01±0.00	0.005
BOD (mg/l)	4.07±0.15^{m}	0.37±0.11^{o}	4.20±0.10^{n}	2.43±0.15	17.67±0.58	5.75±0.03	30
Bacterial count (CFU/100ml)	8.67±0.58^{n}	26.33±1.52^{p}	23.33±2.08^{o}	71.33±1.52^{j}	61.67±0.58	38.27±0.57	5-10
Coliform count (cfu/100ml)	11.67±0.58^{o}	21.00±1.00^{q}	13.67±1.52^{p}	44.00±1.00^{k}	46.00±1.00	27.27±0.07	10
E.coli (cfu/100ml)	2.67±0.58^{p}	8.67±0.58^{r}	7.67±0.58^{q}	8.67±1.53	15.00±0.00	8.54±0.04	0

Table 3. Comparison of groundwater physicochemical and microbial parameters in Izombe with WHO standard

PARAMETERS	IZOMBE	WHO	T-TEST	P-VALUE
Temperature °C	28.09±0.15	20-30	13.60	<0.001
Conductivity (µs/cm)	25.82±0.14	100	15.06	< 0.001
Colour (PCU)	23.89±0.25	15.00	0.937	0.404
Turbidity (NTU)	7.59±0.02	5.00	0.583	0.591
Ph	6.42±0.28	6.5-8.5	0.216	0.840
Dissolved Oxygen (mg/l)	6.93±0.09	>4	5.813	0.004
Total dissolved solids (mg/l)	16.76±0.04	250	74.828	< 0.001
Total suspended solids (mg/l)	5.14±0.15	50	19.348	<0.001
Chlorine (mg/l)	0.16±0.02	0.2-0.25	2.054	0.109
Nitrate (mg/l)	59.56±0.50	40.00	1.024	0.364
Nitrate-Nitrogen (mg/l)	13.89±0.3	15.00	0.267	0.803
Ammonia (mg/l)	0.29±0.07	0.30	0.076	0.943
Phosphate (mg/l)	0.88±0.03	5.0	24.65	<0.001
Phosphorus (mg/l)	0.28±0.02	0.3	0.324	0.762
Sulphate (mg/l)	5.13±0.15	100	268.0	<0.001
Zinc (mg/l)	0.02±0.01	5.0	734.8	<0.001
Alkalinity (mg/l) $CaCO_3$	27.92±0.03	200	14.97	<0.001
Chromium (mg/l)	0.01±0.00	0.05	11.23	<0.001
Calcium (mg/l)	0.17±0.02	150	753.4	<0.001
Magnesium (mg/l)	0.002±0.01	150	7499	<0.001
Iron (mg/l)	0.33±0.01	0.3	0.178	0.867
Copper (mg/l)	2.37±0.03	1.0	1.022	0.365
Lead (mg/l)	0.50±0.01	0.05	3.355	0.028
Nickel (mg/l)	0.00±0.00	0.02	0.000	-
Aluminium (mg/l)	1.65±0.02	0.20	14.73	<0.001
Mercury (mg/l)	2.35±0.04	0.002	3.144	0.035
Manganese (mg/l)	0.22±0.01	0.2	0.333	0.756
Cadmium (mg/l)	0.00±0.00	0.005	0.000	-
BOD (mg/l)	4.92±0.01	30	12.34	<0.001
Bacterial count (cfu/100ml)	27.53±0.58	5-10	0.218	0.838
Coliform count (cfu/100ml)	14.99±0.24	10	0.691	0.528
E.coli (cfu/100ml)	6.93±0.29	0	1.765	0.152

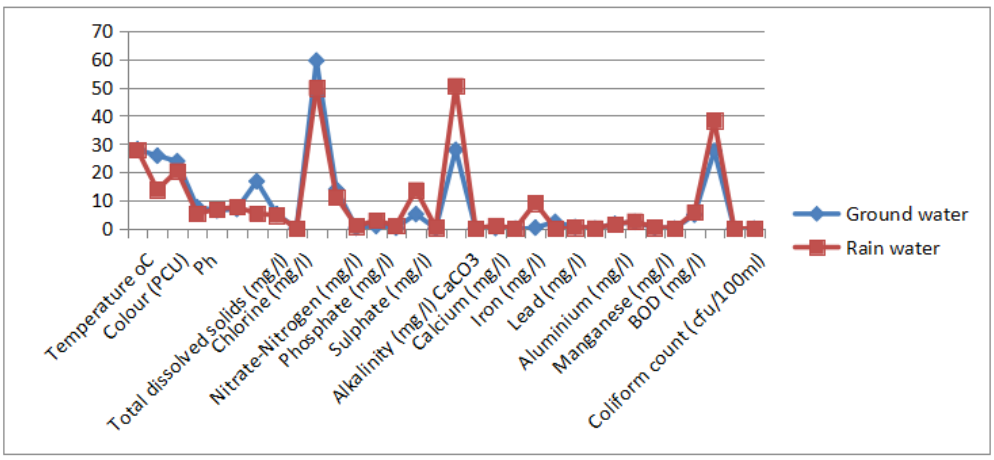

Figure 1. Comparison of groundwater and rainwater physicochemical and microbial parameters in Izombe

DOI: https://doi.org/10.30564/jees.v3i2.3582

Table 4. Comparison of rainwater physicochemical and microbial parameters in Izombe with WHO standard

PARAMETERS	IZOMBE	WHO	T-TEST	
Temperature °C	27.94±0.13	20-30	3.2	0.033
Conductivity (µs/cm)	13.77±0.12	100	11.54	< 0.001
Colour (PCU)	20.47±0.35	15.00	0.699	0.523
Turbidity (NTU)	5.36±0.03	5.00	0.466	0.665
Ph	6.80±0.16	6.5-8.5	0.590	0.587
Dissolved Oxygen (mg/l)	7.72±0.9	>4	11.701	<0.001
Total dissolved solids (mg/l)	5.29±0.03	250	236.5	< 0.001
Total suspended solids (mg/l)	4.73±0.21	50	22.38	<0.001
Chlorine (mg/l)	0.07±0.01	0.2-0.25	9.46	0.001
Nitrate (mg/l)	49.82±032	40.00	1.254	0.278
Nitrate-Nitrogen (mg/l)	11.22±0.10	15.00	2.101	0.103
Ammonia (mg/l)	0.88±0.03	0.30	2.099	0.104
Phosphate (mg/l)	2.89±0.04	5.0	0.966	0.389
Phosphorus (mg/l)	0.97±0.02	0.3	0.963	0.390
Sulphate (mg/l)	13.73±0.08	100	36.66	<0.001
Zinc (mg/l)	0.34±0.01	5.0	42.29	<0.001
Alkalinity (mg/l) $CaCO_3$	50.67±0.06	200	25.90	<0.001
Chromium (mg/l)	0.01±0.00	0.05	0.000	-
Calcium (mg/l)	1.09±0.02	150	467.03	<0.001
Magnesium (mg/l)	0.03±0.01	150	179.6	<0.001
Iron (mg/l)	9.05±0.01	0.3	1.170	0.307
Copper (mg/l)	0.08±0.02	1.0	23.09	<0.001
Lead (mg/l)	0.39±0.01	0.05	1.808	0.145
Nickel (mg/l)	0.17±0.02	0.02	1.680	0.168
Aluminium (mg/l)	1.52±0.03	0.20	5.875	0.004
Mercury (mg/l)	2.64±0.01	0.002	4.075	0.015
Manganese (mg/l)	0.34±0.02	0.2	1.035	0.359
Cadmium (mg/l)	0.01±0.00	0.005	0.250	0.815
BOD (mg/l)	5.75±0.03	30	7.925	0.001
Bacterial count (cfu/100ml)	38.27±0.57	5-10	2.354	0.078
Coliform count (cfu/100ml)	27.27±0.07	10	2.330	0.080
E.coli (cfu/100ml)	8.54±0.04	0	4.351	0.012

4. Discussion

4.1 Physico-chemical Quality of Izombe Rainwater

The presence of color and turbidity in rainwater in Izombe is brought about by industrial pollution occasioned by gas flair and petrochemical products and the high level of nitrates and ammonia lead to acid rain in Izombe. A high level of heavy metals such as iron, lead, nickel, aluminum, mercury, and cadmium in the area is due to the oil exploratory activities by the use of heavy-duty machinery. Communities located closer to the oil wells such as Ugbele and Ndioko show a higher level of rainwater contamination of iron with values of 90+0.01 mg/l for Ugbele and 1.25+0.01 mg/l for Ndioko as against the WHO standard value of 0.3 mg/l. Ugbele community showed a markedly high level of contamination of rainwater with mercury with the value of 3.13+0.12 mg/l when compared with other communities located far away from the oil wells such as Umuakpa with the value of 0.21+0.02 mg/l. (Table 1).

The results of the physicochemical parameters of rainwater in Izombe show that color and turbidity gave higher values than the WHO's acceptable standard value. Turbidity was related to the presence of particles of clay, organic components, and other microscopic substances that make the water unhealthy for human consumption. The findings [11], it is an indication of deposits of pollutant loads or dissolved particles. In Izombe as an oil-producing

DOI: https://doi.org/10.30564/jees.v3i2.3582

community, rainwater turbidity is commonly due to the dissolution of particulate matter, generated from oil production emissions. The total dissolved solids (TDS) and conductivity values in rainwater are generally lower than that of groundwater.

The high value of Nitrate in the rainwater constitutes acidity in water found in the area. The source is traced to the dissolution in rainwater of acidic gases including CO_2, NO_2, and SO_2 that originate from gas flares, industrial generators, and vehicular exhaust fumes [12]. Ammonia was found to be of a very high level beyond WHO's acceptable standard value in rainwater. This is an indication of the high rate of atmospheric pollution by gas fumes from industrial sources.

4.2 Microbial Quality of Izombe Rainwater

The sanitary quality of rainwater in the study area was assessed by its bacteriological composition. In Table 2, which shows that the bacteria count, coliform, and E-coli are exceptionally higher than the WHO values? The presence of these microbes may partly be explained by the mode of sample collection and partly by the fact that the aqueous particulates in the atmosphere can harbor spores of microorganisms that are washed down during rainfall. Rainwater samples were collected directly into containers as they fell through the atmosphere. Usually, serious microbial contamination only begins after contact with collection surfaces, such as roofing materials [13].

4.3 Physico-chemical Quality of Izombe Groundwater

The presence of color and turbidity in groundwater in Izombe is brought about by industrial pollution occasioned by gas flair and petrochemical products and the high level of nitrates and ammonia lead to acid rain in Izombe. A high level of heavy metals such as iron, lead, nickel, aluminum, mercury, and cadmium in the area is due to the oil exploratory activities by the use of heavy-duty machinery.

Ugbele community located closer to oil wells showed a markedly higher level of contamination of groundwater with mercury with values of 5.02+0.06 mg/l when compared with other communities located far away from the oil wells such as Umuakpa with a value of2.30+0.10 mg/l.

The results of the physicochemical parameters of groundwater in Izombe agree with the opinions of [14], who stated that turbidity can be related to the presence of particles of clay, organic components, and other microscopic substances that make the water unhealthy for human consumption. The findings of [11], it is an indication of deposits of pollutant loads or dissolved particles. In Izombe as an oil-producing community, groundwater turbidity is commonly due to the dissolution of particulate matter, generated from oil production emissions which when dissolved in rainfall return back to the ground and thus polluting the aquifer. The total dissolved solids (TDS) and conductivity values in rainwater are generally lower than that of groundwater. Ammonia was found to be of a very high level beyond WHO's acceptable standard value in groundwater. This is an indication of the high rate of atmospheric pollution by gas fumes from industrial sources which later find their way into the soil.

4.4 Microbial Quality of Izombe Groundwater

The microbial contamination of groundwater in the area is attributable to the unsanitary habits of the inhabitants.

The sanitary quality of groundwater in the study area was assessed by its bacteriological composition. Tables 1and 2 indicate that the bacteria count, coliform, and E-coli are exceptionally high in groundwater when compared with the WHO standard values. Results obtained from groundwater samples indicate high total coliform counts that exceed the [5] standard for water portability. The high coliform counts suggest that groundwater in the study area may be potentially harmful. The ingress of coliform bacteria may have been facilitated by the shallow nature (0 - 4.3 m) of the aquifer, which enables easy access by percolating contaminated water.

4.5 Environmental and Health Implications

The result of this study and several others indicate that the accelerated economic and population growth brought about by the oil exploration and production activities in the study area gave rise to adverse environmental and health impacts.

The massively enhanced values of SO_4^{2-} and NO^{3-} in rainwater relative to groundwater indicates quality degradation in rainwater and suggests substantial pollution of the atmosphere from which SO_2 and NO_2 gases were scavenged by the falling rainwater. SO_2 and NO_2 gases are actively poisonous and irritating both to the skin and lungs. Besides, SO_2 and NO_2 are dissolved by rainwater to produce weak H_2SO_4 and HNO_3, which fall on the earth as acid rain, with corrosive effects. Recent studies indicate that SO_4^{2-} and NO^{3-} contributed more than 75% of free acidity in rainfall in the Izombe area [12].

Secondly, the result of acid rain in the study area is evident. Visual observation showed that stationary structures, roofing sheets, and other metallic objects are usually very rapidly weathered thereby reducing their

DOI: https://doi.org/10.30564/jees.v3i2.3582

shelf life. Also, the gaseous emissions have been linked to the increased greenhouse effect and the establishment of local heat islands in the area. The atmospheric content of greenhouse gases of CO_2, CO, NO, NO_2, SO_2, and C_{l2} in built-up and petroleum industrial areas is significantly higher than in the countryside [15]. These areas are consequently warmer by about 9^0C during the day and 2^0C at night and are less humid by about 15% relative to the countryside.

The measured Lead (Pb) concentrations of rain and groundwater samples are higher than [5] recommended maximum value. The toxic effects of excessive Lead (Pb) levels in humans include significant damage on the brain of both adults and infants [16]. It is also known to induce heart-related diseases [17].

Furthermore, the rapid population growth that outpaced public utility development and the unsanitary habits of the residents is reflected in the high coliform load in groundwater within the study area. Although the water samples were not tested for specific pathogens, the high microbial population present suggests that it may be harmful to health.

4.6 Conclusions

From the study, there is an agreement among scholars that water quality is determined by the degree or value of pollutants present. To this end, the researcher in his findings indicates that there are pollutants in varying levels in Izombe rain and groundwater. The values of these measured parameters in rain and groundwater were however compared with their values with WHO standards. The differences in values of the pollutants found in rainwater from those in groundwater may be explained as the result of their different sources as well as the movement of the pollutants.

The laboratory results show that the groundwater had higher values of Copper, Nickel, Lead and Mercury iron, Aluminum, BOD, Bacterial count, Coliform, and E-Coli than rainwater. The total dissolved solids, gases, and chemicals also went beyond acceptable WHO standards, thereby constituting groundwater pollutants in Izombe. Rainwater recorded a greater value of Turbidity, Sulphate, Nitrate, Phosphorous, Ammonia, and Manganese, than groundwater and far beyond the acceptable limit by WHO standard. These parameters are therefore the registered rainwater pollutants in Izombe.

Based on the [5]specifications, the groundwater cannot, therefore, be acceptable as potable owing to its high coliform counts, bacterial and other impurities from dissolved solids, gases, and chemicals, while enhanced Turbidity, Sulphate, Nitrate, and Phosphorous concentration, on the other hand, makes the rainwater acidic and so objectionable.

4.7 Recommendations

The researcher wishes to recommend as follows:

Earlier, the government of Nigeria had set the year 2008 to end all gas flaring activities by oil companies operating in the Niger Delta area. But this failed to fruition. All relevant authorities should put machinery in motion to ensure that these health and environmental hazardous activities are stopped.

Local communities, especially oil company hosts, should be very conscious of their environment, avoid and prevent unhealthy practices mostly such that generate water pollution.

There should be enforced and supervised better sanitation practices in the rural and urban communities.

The degenerating trend of water resources quality in our community should be reversed.

Bush burning and chemical farming should be put under strict control.

Oil and gas producing and processing companies should be made to pay commensurable compensation to host communities like Izombe for being the principal architect of their health and environmental disorder.

Conflicts of Interest

The author hereby declares that he has no conflict of interest.

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DOI: https://doi.org/10.30564/jees.v3i2.3582

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Journal of Environmental & Earth Sciences
https://ojs.bilpublishing.com/index.php/jees

ARTICLE

Efficacy of Acid-treated Sawdust in Decolourization of Tanning Wastewater

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ARTICLE INFO

Article history
Received: 7 September 2021
Accepted: 23 September 2021
Published Online: 8 October 2021

Keywords:
Wastewater
Acid-modification
Sawdust
Physicochemical properties

ABSTRACT

Colour removal from dye-bearing effluent is a serious challenge due to the difficulty in treating such wastewater by conventional treatment methods. The present investigation explores the decolourization of contaminated wastewater using acid-activated sawdust as an adsorbent. The physicochemical properties of wastewater samples labelled A, B, and C viz average temperature; pH; electrical conductivity; and total dissolved solids were determined using standard methods to be 302.63; 6.1; 284.47 µS/cm; 35116.66 mg/L respectively. Colour removal efficiency of the adsorbent was studied under variable conditions (contact time, rate of agitation, loading). Experimental results demonstrated that the sawdust adsorbent has a significant capacity for colour removal from tannery effluent. There was significant variation in the absorbance of the treated samples. Adsorbent dose, stirring rate, and contact time were found to be directly proportional to colour removal while pH variation of the samples show that the effluents became less alkaline (slightly acidic) after decolourization.

1. Introduction

Diverse environmental and anthropogenic pollution have been posed by Chemical industries producing waste effluents for over a decade. These effluents are a major threat to the environment as they appreciably affect green industrial activities and are unquestionably one of the most important problems of industrialization [1].

Tanning, the chemical process that converts animal hides and skin into leather and related products, is usually achieved employing tanning agents and the process generates highly turbid, colored, and foul-smelling wastewater. The major components of the effluents include large quantities of solid waste, sulfides, volatile organic compounds, suspended solids like animal hair, etc [2].

The uncontrolled release of tannery effluents (containing high COD, BOD levels, trivalent chromium, sulfides, sodium chloride, calcium, magnesium, organics, and other toxic ingredients) to the natural water bodies affect the plant and animals, the ecosystem and increases the health risk of human beings [3,4].

Development of profitable and economically feasible way of curtailing the effects of tannery effluents cannot be overemphasized especially using local waste materials as precursors. Literature by [5-7], reported an estimated production capacity of 1.8 billion metric tons of leather yearly, with a larger part of the product processed in Africa and Asia, factored by the high labour intensity involved in the manufacture and treatment of leather.

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 DOI: https://doi.org/10.30564/jees.v3i2.3699

According to reports of [8,9], colour removal in wastewater is one of the most difficult challenges to be addressed by textile finishing, tanning, dye manufacturing, pulp, and paper industries, among others.

Over the last few years, adsorption has gained importance as a separation, purification, and or detoxification process on an industrial scale. It has been used to purify [2], decolorize [6-8], detoxify [12], deodorize [2], separate [4], concentrate [5], and recover the harmful products from liquid solutions and gas mixtures [9].

Aerobic digestion is based on consumption of organic matter and its degredation to produce single cell protein, CO_2 and water. Anaerobic digestion (AD) incorporates a series of interdependent biochemical reactions through the metabolic pathways of anaerobic microorganisms in the absence of air (oxygen). It is used as a pre-treatment step to improve efficiency and valorize organic mill waste (OMW) to achieve up to 80-85% COD, 59-87% reduction in toxicity, 65-95% removal of total phenols etc. Accordingly, Sungur and Özkan [10], considered adsorption processes one of the best choices compared to other methods due to its convenience, ease of operation, simplicity of design, high efficiency, and wider applicability in water pollution control.

2. Experimental

2.1 Sample Collection and Treatment

The sawdust was collected from a local sawmill in Sokoto State. It was carefully screened, washed several times with distilled water to remove dirt (sand dust), colour and other surface adhering particles, filtered, dried in a thermostatic oven at 105 ^oC [26].

The dried sample was ground to smaller particles size with a mechanical blender and used for the preparation of the adsorbent. The tannery wastewater that was used was collected from a local tannery located at Tudun Wada and Bauchi Road areas of Sokoto State. The method of collection was by direct dipping of a 2 L plastic bottle into different depths of the effluent. The bottle was removed, covered, and brought to the laboratory for analysis. Adopting the method reported by [27] the temperature, pH, total dissolved solids and conductivity were determined as soon as the samples were brought to the laboratory. The samples were used as obtained without any treatment.

2.2 Preparation of Adsorbent

The method reported elsewhere [2] was adopted for preparing the adsorbent. Powdered sawdust (150 g) was accurately weighed using an analytical balance and transferred into an empty 1000 cm^3 beaker where 500 cm^3 of 5 % sulfuric acid (H_2SO_4) solution was added. The mixture was placed on a magnetic stirrer/heating mantle for continuous stirring and heating at 32 ^OC for 24 h until a thick slurry was obtained. The slurry (acidified sawdust) was washed (continuously) with distilled water until a weakly acidic pH of more than 5. The acid-treated sawdust was dried in a thermostatic oven at 50 ^oC overnight and then stored in a glass container before further investigations.

2.3 Decolourization

Tannery wastewater was used to evaluate the effectiveness of the acid-modified sawdust for decolourization. The temperature, pH, conductivity, total dissolved solids, and colour of the tannery effluents were determined before and after the adsorption process. The physical properties of the effluent viz temperature, pH, and conductivity were analyzed using a mercury thermometer, digital pH meter (Model KL-03l), and a conductivity meter respectively. Total Dissolved Solid was tested as per APHA standards. The adsorption studies were carried out at variable contact time (seconds), adsorbent dosage (g), and agitation speeds (revolutions per minute, rpm). Decolourization of the wastewater was carried out using the batch method as described elsewhere [28].

2.4 Adsorption Experiments

Effect of Variable Adsorbent Dosage

Wastewater sample (100 cm^3 each) was accurately measured and transferred into 3 containers (500 cm^3 beakers) labelled A, B, and C. Adsorbent dosage of 5 g, 10 g, and 15 g at a constant agitation speed of 120 rpm and contact time of 300 seconds were added to A, B, and C respectively. The mixtures were filtered and the filtrate was analyzed for the extent of decolourization.

Effect of Agitation Speed /Stirring Rate

To a similar set of beakers labelled A, B, and C, having 100 cm^3 each of wastewater maintained for 300 seconds, containing 10g of adsorbent each, the stirring rate was varied to 100 rpm, 120 rpm, and 140 rpm in A, B and C respectively. The mixture was filtered and the filtrates were analyzed for the extent of decolourization.

Effect of Contact Time

Wastewater samples (100 cm^3) placed in beakers labelled A, B, and C containing 10 g each of the adsorbent stirred at 120rpm were maintained for 10, 20, and 30 minutes respectively.

The absorbance of the tannery wastewater was obtained

  DOI: https://doi.org/10.30564/jees.v3i2.3699

using a UV-VIS spectrophotometer (Spectrum lab 23A) at a pre-optimized λ_{max} (wavelength corresponding to maximum absorption) as described by [1]. After equilibration and filtering of the adsorbent, the adsorbate solutions were examined for the extent of decolourization through the differences in absorbance.

3. Results

3.1 Result of Physicochemical Parameters

The result of physicochemical parameters of the tannery wastewater before and (after) decolourization is presented in Table 1.

Table 1. Physiochemical Parameters of Tannery wastewater

	Samples			
Parameter	**A**	**B**	**C**	**SPL (WHO, 2002)**
Temperature (K)	302.5 (296.7)	302.8 (299.5)	302.6 (296)	N/A
pH	5.2 (5.78)	5.3 (5.96)	7.8 (8.77)	6.5 - 9.5
Electrical Conductivity (µS/cm)	15.62 (25.89)	15.98 (32.76)	821.83 (850.01)	1200
Total Dissolved Solids (mg/L)	53470 (5005)	23230 (5235)	28650 (5306)	2100
Colour	Brown (Cloudy)	Brown (Cloudy)	Brown (Cloudy)	Light Permeable

SPL: Standard Permissible Limit [1]; values before and (after) adsorption.

3.2 Results of Predetermined λ_{max}/Absorbance

Table 2 presents the absorbance of samples at a predetermined wavelength (630 nm).

Table 2. Sample Absorbance at Predetermined Wavelength

Sample	λ_{max} (nm)	Absorbance
A	490 (204)	2.232 (0.929)
B	410 (186)	2.146 (0.973)
C	490 (201)	0.094 (0.038)

Values before and (after) decolourization.

3.3 Result Variable of Adsorbent Dosage

Table 3 shows the absorbance (at 490 nm) of the various wastewater samples after treatment.

Table 3. Absorbance of Samples with Variable Adsorbent Dosage

Adsorbent Dosage (g)	Absorbance		
	A	**B**	**C**
5	1.873	1.913	0.04
10	1.635	1.649	ND
15	1.216	1.107	ND

ND= Not Detected

3.4 Result of Variable Agitation

Table 4 presents the absorbance of the wastewater samples after treatment, at variable agitation speed.

Table 4. Absorbance of Samples at Variable Agitation Speed

	Absorbance		
Agitation Speed (rpm)	**A**	**B**	**C**
100	1.220	1.121	ND
120	1.209	1.101	ND
140	1.188	1.098	ND

ND= Not Detected

3.5 Result of Variable Contact Time

The absorbance (at 490 nm) of the various wastewater samples after treatment, by varying the contact time at an agitation speed of 120 rpm and constant adsorbent dosage of 10 g is presented in Table 5.

Table 5. Effect of Contact time at 120 rpm and Adsorbent Dosage of 10 g

	Absorbance		
Contact Time (min)	**A**	**B**	**C**
10	1.162	1.083	ND
20	1.137	1.049	ND
30	1.121	1.037	ND

ND=Not Detected

4. Discussion

The physicochemical characteristics of the tannery wastewater were reported in Table 1. The average recorded temperatures (K) before and after are 302.63 and 297.4 K respectively. This informs that clarity obtained leads to a decrease in suspended solids which makes the samples colder (lower temperature). The temperature obtained for samples A, B, and C in this study is higher compared to 296.9 K reported by [29]. The slight temperature difference showed a gradual appreciable pattern of decrease. In this study, average pH of 6.1 and 6.83 was recorded for the

DOI: https://doi.org/10.30564/jees.v3i2.3699

samples before and after decolourization. However, [30] reported a pH value of 10.5, which is greater than the values recorded for the studied samples. The average pH value of 6.8 close to 7.8 recorded for sample C was also reported by [31]. This shows that the degree of acidity or alkalinity of tannery wastewater can vary greatly depending on the concentration of chemicals. The slight decrease in acidity in the pH values shows that the effluents became less alkaline (slightly acidic) after use. This confirms that they can be used for shaving hairs from the skins of animals. The pH values recorded for the wastewater in this study are within the standard discharge limit of 6.5 - 9.5 as shown in the standard permissible limit (SPL) by the World Health Organization (WHO).

The electrical conductivity (EC) recorded in μS/cm for the samples are 15.62, 15.98, and 821.83 accordingly while 25.89, 32.76, and 850.01 for treated samples respectively. The values for electrical conductivity (EC) in samples A (25.89) and B (32.76) are lower compared to 850.01 recorded in sample C. However, the three samples recorded an EC value that is within the standard of 1200 μS/cm stipulated for the discharge of wastewater into the environment. These values are low compared to 1348 μS/cm recorded by [1]. The variation in the total electrical conductivity may be dependent on the different kinds of chemicals used in the different stages of the tannery processes. The amount of total dissolved solids (TDS) recorded for samples A, B and C are in the order 53470, 23230, and 28650 mg/L respectively. Reports by [2] and [31] presented lower TDS values of 14020mg/L and 1318 mg/L respectively. Compared to the values of 2100 mg/L reported as the standard discharge limit for wastewater, values in this finding are much higher, which means that the tannery wastewater samples were quite polluted; samples A B and C are brownish in colour but became cloudy after decolourization.

Table 2 presents the results of the predetermined wavelength (630 nm) of maximum absorption (Lambda max) and their corresponding absorbance values. The extent of colour removal was assessed based on the difference in absorbance of the sampled wastewater. Distilled deionized water was used as blank while the different wastewater samples were analyzed at 630 nm. The observed Lamda max (λ_{max}) for the respective samples may be due to the various absorbing molecules contained in the sample solution. Samples A and C recorded absorbance of 490 nm each, before adsorption and 204 and 201 nm respectively after adsorption. By this similarity in absorbance, samples A and C likely contain similar absorbing molecules (though at different concentrations) than sample B whose absorbance is 410 nm. The best condition for the colour removal of the wastewater samples is thus established from the initial absorbance obtained for the untreated tannery wastewater. This means that reduction in the absorbance obtained for the untreated wastewater samples was regarded as an indication of colour removal capability of the prepared adsorbent.

Table 3 displays the result of variable absorbance recorded for samples, A, B, and C, at stirring speed of 120 rpm for 5 min while the adsorbent dosages varied at 5, 10, and 15 g respectively. The colour removal efficacy of the prepared adsorbent was determined at a different dosage. It was observed that upon subjecting the samples to stated conditions and 5g of the adsorbent, the absorbance values obtained were 1.873, 1.913, and 0.04. When the adsorbent load was increased to 10 g, there was a decrease in the absorbance values for samples A and B to 1.635 and 1.649 while there was no absorbance detected for sample C. Further increase in the adsorbent loading resulted to a decrease in absorbance values while there was no absorbance for sample C. This shows that adsorbent dosage is a significant factor in the removal of colour from tannery wastewater.

A difference of 0.238 in absorbance is noticed when the dosage is increased from 5 g to 10 g and 0.419 from 10 g to 15 g for sample A respectively. For sample B, the difference in absorbance values is 0.264 and 0.542 respectively, when the load was increased from 5 g to 10 g and from 10 to 15 g.

The efficiency of the colour removal increased from 16.08 % to 45.52 % for sample A; from 10.86 % to 48.42 % while it increased from 57.45 % to 100 % for sample C with increasing adsorbent dosage from 5 to 15 g for all samples. According to Sharma and Uma [33], adsorption increased from 86.75 to 99.83 % with increasing adsorbent dose from 0.40 to 0.60 g. Accordingly, [34] also reported an increase in removal efficiency for MB dye with an increasing amount of adsorbent.

The effect of stirring speed on colour removal of the samples, A, B, and C was presented in Table 4. Different agitation rates of 100, 120 and 140 rpm at an adsorbent load of 10g for 300 seconds. 10 grams of adsorbent was used because it gave the best colour removal capability from the previous experiment. At the speed of 100 rpm, the absorbance values of 1.220 and 1.121 were recorded for samples A and B while sample C does not show any absorbance. When the stirring speed was increased to 120 rpm there was a slight decrease in the absorbance of the samples. A further increase in the stirring speed also resulted in a decrease in the values of the absorbance. Significant variation in absorbance values is attributed to

DOI: https://doi.org/10.30564/jees.v3i2.3699

shooting up of the stirring rate from 100 rpm to 120 rpm and 120 rpm to 140 rpm.

Although the effects are not well pronounced as revealed by the present investigation, probably due to saturation and exhaustion of the binding sites on the adsorbents [32-33].

Furthermore, the effect of contact time on colour adsorption by the prepared adsorbent was investigated. Table 5 shows the absorbance of samples A, B, and C, with an adsorbent load of 10 g at a stirring speed of 120 rpm for a period of 10 min, 20 min and 30 min respectively. For sample A, the absorbance dropped from 1.162 to 1.137 and further 1.121 at a contact time of 10 min and stirring speed of 120 rpm.

Sample B recorded a drop in value of absorbance from 1.083 to 1.049 and finally to 1.037 from 30 to 20 to 10 minutes respectively. Reduction in values of the absorbance is an indication of colour removal by the prepared adsorbent. The efficiency of removal is assessed by the level of reduction in the absorbance. It is obvious from Table 5 that time is an important parameter for the adsorption of colour on activated sawdust. The activated sawdust is also very effective in the removal of colour from sample C.

5. Conclusions

Based on the research findings, it can be seen that adsorbent dosage, stirring speed as well as contact time are all important factors in colour removal from wastewater. The adsorbing molecules of the constituent of coloured solution may also affect the efficiency of colour removal.

Adsorption of colour was influenced by various parameters such as adsorbent dosage, agitation speed, and contact time. Adsorption increased with increasing the quantity of adsorbent over an extended time and it was also observed that the efficiency of colour removal was concentration-dependent. The present investigation proved that adsorbents made from sawdust can be employed for the decolourization of tannery wastewater and will add to the existing technology of waste minimization. However, in order to establish its effectiveness, the current findings should be verified on an industrial (large) scale.

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DOI: https://doi.org/10.30564/jees.v3i2.3699

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Journal of Environmental & Earth Sciences
https://ojs.bilpublishing.com/index.php/jees

REVIEW

Sequential Damming Induced Winter Season Flash Flood in Uttarakhand Province of India

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ARTICLE INFO

Article history
Received: 8 April 2021
Accepted: 12 October 2021
Published Online: 30 October 2021

Keywords:
Himalaya
Uttarakhand
Flash flood
Landslide dam
Landslide lake outburst flood (LLOF)
Dam breach

ABSTRACT

204 persons were killed while two hydropower projects located in close proximity at Rishiganga (13.2 MW), and Tapoban (520 MW) were damaged in Dhauliganga flood of February 7, 2021 in the Indian Himalaya. This incidence occurred during the winter season when the discharge of the glacier fed rivers is minimal, and no rain was experienced in the region around the time of the flood. Despite discharge of the main river, Rishiganga, not involved in the flood due to damming upstream of its confluence with Raunthi Gadhera, based on field evidences massive volume of around 6 million cu m water involved in this flood is attributed to sequential intermittent damming at three different places; (i) Raunthi Gadhera was dammed first in its upper reaches, (ii) Rishiganga river was then dammed to the north of Murunna, and (iii) finally Dhauliganga river was dammed around Rini village to the upstream of its confluence with Rishiganga river. Lacking warning system only enhanced the flood-induced devastation. Legally binding disaster risk assessment regime, together with robust warning generation, and dissemination infrastructure are therefore recommended for all major infrastructure projects.

1. Introduction

Continuity of tectonic movements, evolutionary history, and geomorphic setup of the terrain, together with peculiar meteorological conditions make the Himalayan region vulnerable to a number of hazards.

Located in the central sector of the Himalaya to the west of Nepal (Figure 1), Uttarakhand province in India is routinely devastated by flash flood, flood, landslide, and cloudburst incidences (Table 1), particularly during the monsoon period (mid-June to mid-September) when the region experiences heavy precipitation due to SW monsoon.

These losses are often associated with localised heavy rainfall events, referred as cloudburst, that have registered a marked increase in the Himalayan region during the previous decade, and are often attributed to climate change [1-3]. Ensuing sudden increase in the discharge of streams sometimes results in flash flood conditions, and during the monsoon period of 2010, 2012, and 2013 Uttarakhand witnessed major devastation due to these [4]. Cloudburst is however not the only cause of flash floods, and the region has witnessed incidences wherein streams have been blocked by landslides, and subsequent release

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DOI: https://doi.org/10.30564/jees.v3i2.3069

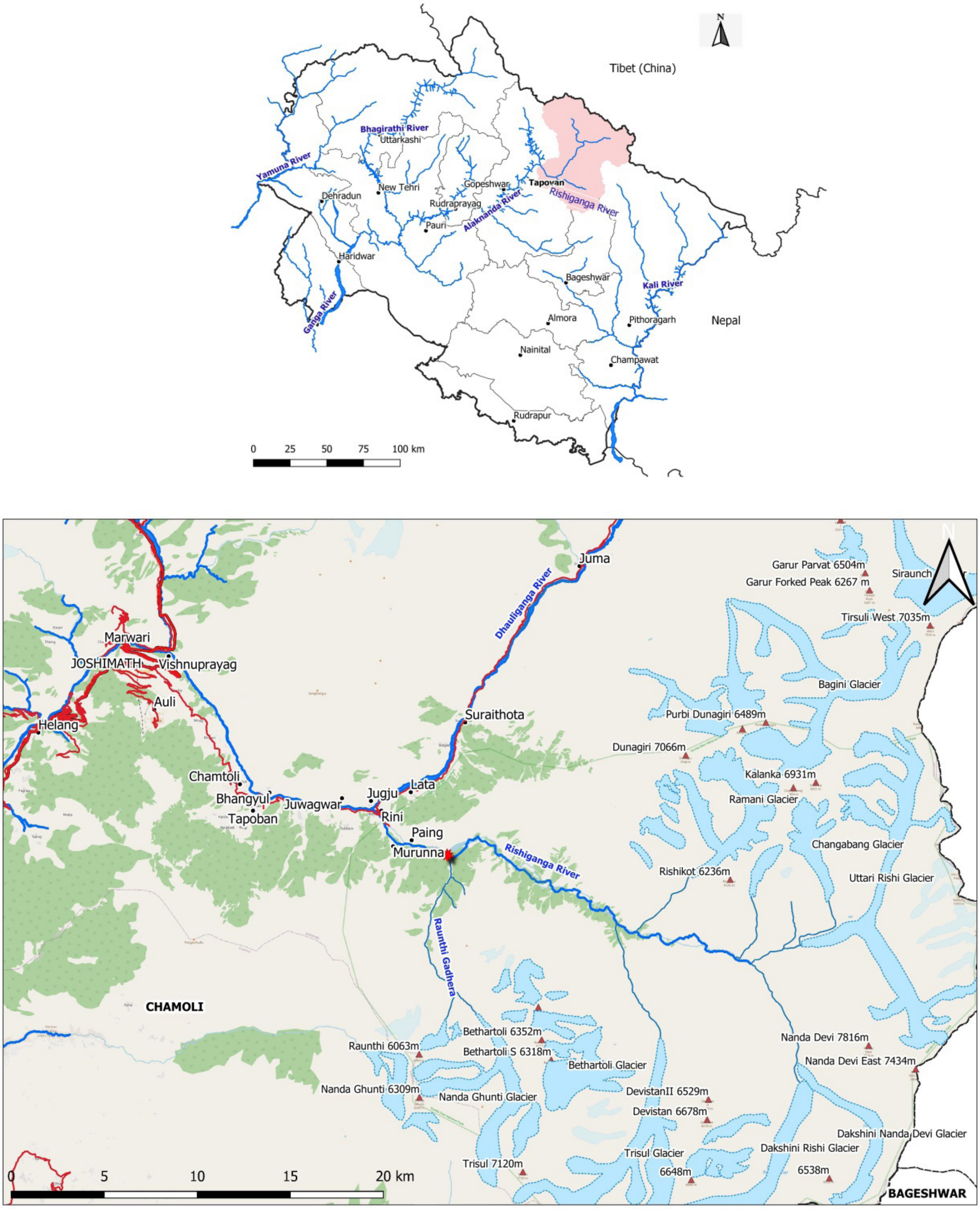

Figure 1. Map of Uttarakhand with Dhauliganga valley highlighted (above), and map of Dhauliganga valley (below).

DOI: https://doi.org/10.30564/jees.v3i2.3069

Table 1. Disaster induced losses in the Uttarakhand province in the period 2010-21.

Year	Human loss			Number of farm animals lost	Number of houses damaged / destroyed			Loss of Agriculture land (in ha)
	Dead	Missing	Injured		Partially	Severely	Fully	
2010	220	-	139	1,798	10,672	-	1,215	240.9
2011	83	-	71	876	5,814	-	514	806.4
2012	176	-	96	997	743	-	285	40.3
2013	225	4,021	238	11,268	11,938	3,001	2,295	1309.0
2014	66	-	66	371	1,260	278	342	1285.5
2015	55	-	64	3,717	1,313	125	81	15.5
2016	119	05	102	1,391	2,684	839	252	112.3
2017	84	27	66	1,020	1,067	434	101	21.0
2018	100	09	48	764	2,042	433	122	295.4
2019	102	02	78	1,323	571	64	300	238.8
2020	82	03	45	718	448	442	135	1087.1
2021	308	61	105	1,048	715	395	87	18.7
Total	1,620	4,123	1,118	25,291	39,267	6,011	5,729	5,470.9
Average	135	344	93	2,108	3,272	501	477	455.9

Data source: State Emergency Operations Centre (SEOC), Uttarakhand.

of impounded water has caused devastating flash floods (Table 2) [5]. These incidences are generally referred to as landslide lake outburst floods (LLOF).

Alaknanda river valley of Garhwal Himalaya has been particularly vulnerable to LLOFs, and 33% of the reported incidences are associated with Dhauliganga valley (Table 2).

2. Dhauliganga Flood of 2021

The discharge of Rishiganga, and Dhauliganga rivers in Chamoli district of Uttarakhand increased suddenly in the forenoon of February 7, 2021 and the floodwaters washed off a hydropower project of 13.2 MW capacity on Rishiganga river upstream of Rini while to the downstream, dam axis and other structures of an under construction hydropower project of 520 MW on Dhauliganga river at Tapoban were severely damaged (Figure 2). Persons working in these projects were washed off or buried in the debris. At the time of the incidence 30-35 persons were working in a tunnel at Tapoban that was chocked with debris, and these persons could not be rescued.

Even though agriculture is practiced over alluvial, and colluvial terraces on middle, and lower slopes of the valley, habitations in the region are traditionally located at higher elevations and these did not witness direct flood impact. Connectivity of surrounding 13 villages was however disrupted as six bridges were damaged by the floodwaters. Low lying agricultural fields were also damaged while 360 farm animals were lost in this incidence. 09 persons of the surrounding villages (05 of Rini, 02 of Tapoban, and 02 of Ringi) together with 02 personnel of state Police were amongst 204 persons that went missing.

There being no discharge measurement station in the catchment of Dhauliganga river, exact estimates of the flood volume are not available. A gauging station of Central Water Commission (CWC), 18 km downstream of Tapoban on the Alaknanda river at Marwari however recorded discharge of 1670 cumecs at 1100 hrs on February 7, 2021 as against normal discharge of around 41 cumecs. Around 6 million cu m water estimatedly passed through this gauging station in one hour. There being no rainfall, or accompanying flood incidence in the region entire excess discharge of the Alaknanda river at Marwari on February 7, 2021 is attributed to the flood incidence in Dhauliganga river valley.

Thick pile of fluvio-glacial sediments brought down by the floodwaters, were deposited all along the valley. According to the cross section measurements of the Alaknanda river by CWC at Marwari on February 10, 2021 the river bed was risen by 3.09 m. Thickness of the deposited sediments was observed to be more than 12 m at the dam site at Tapoban.

Table 2. Landslide lake outburst flood incidences in Alaknanda river valley of Garhwal Himalaya.

Sl. No.	Date / year of blockade	Place of damming	Date of breach	Remarks
1.	1868	Alaknanda river blocked by landslide upstream of Chamoli [6]	1868 (Duration of impoundment not clear)	2 villages devastated. 70 persons killed
2.	1893	Birahiganga near its confluence with Alaknanda [7]	1893 (Duration of impoundment not clear)	Water impounded to 10-13 m above normal. 2 bridges damaged.
3.	September 6, 1893	Birahiganga river blocked by landslide forming Gohna Tal [8]	August 25, 1894 (Partial breach)	Landslide dam was 350 m high. Life loss averted by regular monitoring, warning Massive loss of property, and infrastructure
4.			July 12, 1970 (Final breach)	Massive loss of infrastructure, particularly at Srinagar
5.	1930	Alaknanda river blocked near Badrinath [9]	1930 (Duration of impoundment not clear)	Water impounded to 9 m above the normal water level Some houses damaged
6.	1957	Dhauligana river blocked near Bhapkund by an avalanche along Dronagiri river [9]	1957 (Duration of impoundment not clear)	The lake was later filled with debris
7.	February 4, 1968	Rishiganga river blocked by landslide near Rini [10,11]	July 20, 1970	Water impounded to 40 m above the normal water level Extensive damage in downstream areas
8.	September, 1969	Alaknanda river blocked partially upstream of Kaliasaur [11]	1969 (Duration of impoundment not clear)	
9.	July 20, 1970	Dhauliganga river blocked near Tapoban by the debris brought down by Dhak Nala [11]	July 20, 1970	Water impounded to 15-20 m above normal water level
10.	July 20, 1970	Alaknanda river blocked near Helang by the debris brought down by Karmanasa Nadi [11]	July 20, 1970	
11.	July 20, 1970	Alaknanda river blocked by landslide near Hanuman Chatti at Badrinath [10,11]	July 20, 1970	Water impounded to 30-60 m above the normal water level Breach caused considerable loss of life
12.	July 20, 1970	Patalganga river blocked by landslide [7,12]	July 20, 1970	Water impounded to 60 m above the normal water level Major flooding in Alaknanda river Belakuchi village washed off
13.	April, 1979	Alaknanda river blocked by avalanche near Bamni village in the proximity of Badrinath [13]	1979 (Duration of impoundment not clear)	The blockade was in the proximity of Badrinath and triggered by avalanche action
14.	2002	Gandhwi river blocked by landslide near Saigari village [14]	2002 (Duration of impoundment not clear)	Dhauliganga river was flooded by the breach, and Saigari village devastated
15.	February 7, 2021	Course of Raunthi Gadhera, Rishiganga and Dhauliganga blocked	February 7, 2021 (Impoundment was for short duration)	204 persons dead Major devastation to two hydropower projects at Rini, and Tapoban

DOI: https://doi.org/10.30564/jees.v3i2.3069

Figure 2. Devastation at the dam site of Dhauliganga hydropower project.

3. Initial Suggestions on the Cause of Flash Flood

According to an online report based on satellite imageries of Planet Lab, rock mass together with some ice got detached along a crack on the flank of Nanda Ghunti at an elevation of 5,600 m asl, and fell to 3,800 m asl initiating a rock and ice avalanche that travelled down the glacier generating vast quantity of dust, which was observed to be smeared to the west of the valley [15]. Energy generated by the impact of the free fall of huge rock mass and ice over almost 1,800 m was held responsible for quickly melting the snow and ice available in the area, and initiating a debris flow that rushed downslope to cause the devastation [15].

Based on the analysis of LISS-IV satellite data Uttarakhand Space Application Centre (USAC), Dehradun informed the provincial government on February 9, 2021 that a lake has come into existence along the course of the Rishiganaga river at a distance of around 06 km upstream of Rini due to the mass movement along Raunthi Gadhera. This report expressed possibility of breach of this lake that could jeopardize safety and security of the persons engaged in rescue work at Tapoban. Efforts were therefore made to assess the threat posed by the lake that breached naturally on February 12, 2021.

On February 10, 2021 Indian Institute of Remote Sensing (IIRS), Dehradun reported sudden disappearance of snow over almost 14 sq km area (Figures 3 and 4), and added that the avalanche triggering the event also involved melting of fresh snow over this area. Apart from the energy generated by the impact of the rock fall [15], presence of water was attributed to abnormal rise in temperature that was ascertained from the WRF model. Volume of water generated in this process was estimated as 2-3 million cu m.

Figure 3. Planet Lab satellite data of the area of February 7, 2021.

Source: Courtesy Dr. Prakash Chauhan, Director, IIRS.

Based on the analysis of Sentinel-2 satellite imageries of February 5 and 8, 2021 IIRS, Dehradun later assessed the volume of rock mass dislodged along a pre-existing crack on the flank of the western peak adjacent to Trishul glacier as 39.67 million cu m. This rock mass reportedly impacted the valley floor 1,456 m below, near the snout of Trishul glacier generating 1.51 X 10^{12} J energy that was assessed to have melted 4.5 million ton ice in 1.5 hours to initiate the flood event.

Figure 4. Planet Lab satellite data of the area of February 6, 2021.

Source: Courtesy Dr. Prakash Chauhan, Director, IIRS.

DOI: https://doi.org/10.30564/jees.v3i2.3069

Wadia Institute of Himalayan Geology (WIHG), Dehradun on February 10, 2021 expressed possibility of temporary blockade of the Raunthi Gadhera due to avalanche debris at an elevation of 3600 m asl for a few hours in the morning hours of February 7, 2021. Breach of this impoundment was put forth as being the cause of the flash flood.

Figure 5. View of the lake formed in Rishiganga river on February 11, 2021.

Source: Courtesy Dr. M.P.S. Bisht, Director, USAC.

International Centre for Integrated Mountain Development (ICIMOD), Kathmandu[16] as also unpublished report of the Glacier and Permafrost Hazards in Mountains (GAPHAZ), based on the analysis of satellite imageries brought forth evidence of an ice or rock/ice avalanche in the same area between September 19 and 26, 2016. Besides frictional melting and liquification of ice, these reports suggested possibility of reactivation of buried ice together with water trapped under and within the 2016 avalanche debris.

4. Methodology

The flood in the Dhauliganga river valley took place during the winter season when the discharge of glacier fed Himalayan streams and rivers is minimum. At the same time this incidence was not accompanied by major rainfall event. In such a situation pinpointing the source of the floodwaters was a major challenge and different reasons were thus put forward for explaining the flood incidence.

None of these reports convincingly explain the source of huge quantity of water required to initiate the flash flood. Moreover, Rishiganga river, with a catchment area of 664 sq km, being the main tributary of Dhauliganga river, was blocked by the debris brought down by the rock fall-avalanche along the Raunthi Gadhera (Figure 5). This implies that the flood resulting in additional discharge of 1,629 cumecs in the Alaknanda river was caused by the Raunthi Gadhera alone. It is not convincing if a small rivulet with catchment area of only 83 sq km could generate enough water to cause this massive flood.

As observed in different satellite imageries rock mass which is estimated as being 39.67 million cu m by IIRS, Dehradun got detached from a higher elevation with some ice mass. No report convincingly puts forth the proportion of ice in this rock mass. Moreover, for initiating a flash flood, melting has to be instantaneous. It is not convincing that frictional forces, and energy generated in the impact could instantaneously melt huge volume of ice to initiate this flood.

All available reports on this event are primarily based on satellite data and have no field evidences to supplement their assertions. Detailed fieldwork was therefore undertaken in the affected area to understand the mechanism of this flood event and convincingly reconstruct the sequence of events resulting in this massive flood incidence so as to suggest a strategy for minimising possibility of similar incidences in future.

Moreover, to validate the assertion of abnormal temperature increase rainfall and temperature data of various observation stations of India Meteorological Department (IMD) and Uttarakhand State Disaster Management Authority (USDMA) was assessed and analysed.

5. Field Observations

Dhauliganga river originates in the proximity of Niti pass, and flows SW till Rini where it has confluence with Rishiganga river which originates from the glaciers of Nanda Devi massif with Nanda Devi (7,817 m) being the highest peak, and flows NW. Originating from around Nanda Ghungti (6,309 m) and flowing N, Raunthi Gadhera is a major tributary of Rishiganga river. From Rini to Chamtoli (1.0 km downstream of Tapoban) Dhauliganga river maintains a tectonically controlled E-W course, and thereafter flows SE to meet the Alaknanda river at Vishnuprayag (Figure 1).

Dhauliganga valley has rugged mountainous topography with high relative relief, and the altitudes vary between 1,450 and 7,817 m asl. Geo-tectonically aligned narrow valleys and gorges are prominent geomorphic features of this area. In the upper stretches of the valley up to Bhapkund, where a hot spring is located, distinct

DOI: https://doi.org/10.30564/jees.v3i2.3069

glacial landforms with characteristic 'U' shaped valleys, outwash deposits, hanging valleys, moraines and cirques are observed. To the downstream, between Jelam and Juma the landforms are observed to be modified by fluvial action with distinct "V" shaped incised valleys and deep gorges. Thick pile of overburden, steep slopes and high precipitation make this stretch prone to mass wastage. Thereafter, Dhauliganga river is observed to flow through a wide valley till Rini, and the valley becomes relatively narrow to the downstream till Tapoban where another hot spring is located. Narrow valley is observed thereafter till Vishnuprayag.

Evidences of previous damming are observed on the left bank of Dhauliganga river on road section close to hot spring at Tapoban. These lacustrine deposits consist of an inter-bedded sequence of sand, silt, and pebbles (Figure 6).

Figure 6. Evidence of ponding on the left bank of Dhauliganga river in the proximity of hot water spring near Tapoban.

Distinct marks of inundation and fresh erosion are observed on both the valley walls of Dhauliganga river upstream of its confluence with Rishiganga river near Rini village at an altitude of 1,960 m asl, for about 1 km. From the impressions on the valley walls the level of the impounded water is assessed as being 3-4 m above the normal river level (Figure 7).

To the N of Murunna (Figure 1), Rishiganga river is observed to have constricted valley configuration. Fresh deposits of debris are observed at this site on both the banks. The inundation and erosion marks observed on the valley walls at this site suggest the floodwaters to have reached 40-50 m above the riverbed (Figure 8).

Upper catchment of Raunthi Gadhera, the source of the floodwaters, could not be approached. Rocky cliff is however observed along the right bank of Raunthi Gadhera while the left bank is covered with thick pile of overburden material. Huge volume of debris comprising of a mixture of ice blocks, rock fragments and morainic material consisting mainly of pebbles, cobbles, and boulders of quartzite, granitic gneiss and mica schist with silty-clayey matrix are observed in the lower slopes in the proximity of Rishiganga river. Fine dust is also observed on the valley walls as also over vegetation.

Figure 7. Erosion marks on the valley walls of Dhauliganga river near its confluence with Rishiganga river (above), and 1 km upstream along Dhauliganga river (below).

Figure 8. Erosion marks on the valley walls of Rishiganga river to the N of Murunna.

 DOI: https://doi.org/10.30564/jees.v3i2.3069

Evidences of previous damming are also observed on the right bank of Raunthi Gadhera upstream of its confluence with Rishiganga river. These lacustrine deposits are observed to consist of an inter-bedded sequence of sand, and pebbles (Figure 9).

Figure 9. Evidence of ponding on the right bank of Raunthi Gadhera near its confluence with Rishiganga river.

Around 500-700 meters upstream of the confluence of Rishiganga and Raunthi Gadhera blockade is observed on Rishiganga river. Huge volume of rock and debris material (Figure 5) dumped there is observed to be around 50 m high and 100 m wide. Presence of embedded ice blocks is also observed in this barrier. Upstream of this barrier a lake is observed on Rishiganga river along a deep gorge carved in very hard quartzitic rocks that have three sets of consistent joints.

6. Meteorological Parameters Preceding the Disaster

Flash flood requires large volume of water to overwhelm the downstream areas, and apart from breach of a lake, presence of water can generally be explained either by rainfall or melting of snow/ice. Meteorological parameters, particularly rainfall, and temperature, in the surrounding area in the period preceding the flash flood incidence are therefore reviewed.

Average precipitation in Uttarakhand during the winter season of 2020-21 was below normal, and except for November 2020 deficiency in average monthly rainfall in all the districts between September 2020, and February 2021 was between 34 and 99%. The precipitation in Chamoli district that houses Dhauliganga valley, as also around the affected area at Tapoban, and Auli (AWS sites of Uttarakhand State Disaster Management Authority) was also much less than normal for the district between September 2020, and February 2021. The affected area however received some precipitation on February 4 and 5, 2021 and higher reaches experienced snowfall that is observed in the satellite imagery of the area (Figure 4).

As inferred by IIRS, Dehradun from WRF model the area did actually witness sharp rise in the temperature on the very day of this incidence; between February 6 and 7, 2021 Tapoban at an altitude of 2,000 m asl experienced rise of 2.8^{o}C and 5.4^{o}C respectively in minimum, and maximum temperature while the rise at Auli (2,600 m asl) was observed to be 6.0^{o}C and 9.6^{o}C respectively.

7. Scenario Reconstruction

Geomorphic conditions in the Dhauliganga valley provide suitable conditions for river blockade and the same is testified by field evidences of damming at two places (Figures 6 and 9). Field evidences further reveal that the flash flood event of February 7, 2021 was accompanied by damming at three different places, besides the one upstream of the confluence of Raunthi Gadhera and Rishiganga river. This facilitated accumulation of enough water, despite discharge of Rishiganga river being cut off, and explains devastating flood during the lean flow season.

7.1 Damming of Raunthi Gadhera

The upper reaches of Raunthi Gadhera being snowbound could not be assessed during the fieldwork. However, authors in line with WIHG, Dehradun assert preliminary blockade in the upper catchment of Raunthi Gadhera by the rock and ice mass detached from a higher elevation, as also morainic deposits mobilized by the impact from the valley floor. The people of the surrounding villages reportedly heard sound of falling rocks around 0200 hrs on February 7, 2021. This is taken as the timing of the initial rock fall and creation of a rock fall-avalanche barrier along the course of Raunthi Gadhera at an altitude of around 3,600 m asl.

Moreover, the region witnessed precipitation on February 4 and 5, 2021 and fresh snow was present in the upper reaches of the catchment on February 6, 2021 (Figure 4). Sharp rise in temperature on the very day of this incidence facilitated fast melting of freshly accumulated snow as also detached ice mass (Figure 3), and this water accumulated upstream of the avalanche debris. As put forth by an unpublished report of GAPHAZ, buried ice and water trapped under and within the 2016 avalanche debris would have also added to this water.

As put forth by various reports another avalanche activity in the upper reaches of Raunthi Gadhera around 1015 hrs on February 7, 2021 resulted in breach of this impoundment. The water generated by frictional forces

DOI: https://doi.org/10.30564/jees.v3i2.3069

and impact of rock fall as suggested by various reports only added to the volume of the flood waters.

7.2 Lake on Rishiganga River

Breach of the avalanche dam in the upper reaches of Raunthi Gadhera resulted in sudden downslope gush of water along steep slope that transported huge volume of glacial material, ice and rock mass. This movement generated a plume of dust that is observed on the valley walls as also over vegetation.

This fast moving debris laden water eroded the valley slope on the left bank of Raunthi Gadhera and the eroded mass added to the debris material transported downstream. Large rounded chunks of ice transported by floodwaters were observed all along the valley slope after many days of the incidence which refute the hypothesis of instant melting of ice resulting in flash flood.

The fast moving and debris, ice and rock mass laden flow of Raunthi Gadhera smashed against the valley wall on the right bank of Rishiganga river (2315 m asl). High angular relationship of these streams caused flow deflection, which facilitated backflow along Rishiganga river and large volume of rock and debris material was transported upstream along Rishiganga river for about 500 - 700 m and dumped there (Figure 5). This barrier cut off discharge of Rishiganga river and the water draining down from Raunthi Gadhera alone flowed downstream along the course of Rishiganga river till February 12, 2021.

7.3 Intermittent Damming N of Murunna

Though the discharge of Rishiganga river was blocked by the debris barrier, the floodwaters of Raunthi Gadhera travelled downstream along the course of Rishiganga river. Field evidences suggest that the course of Rishiganga river was blocked again intermittently to the N of Murunna (Figure 1) by the debris being carried by the floodwaters. Constricted valley configuration at this site facilitated the damming (Figure 8). Deposits of debris are observed at this site on both the banks and evidences on the valley walls suggest that the impoundment was up to 40-50 m above the riverbed.

With discharge of Rishiganga river cut off, but for this impoundment the flood would not have been particularly devastating. It is this damming that ensured accumulation of enough water to devastate the downstream areas. With the breach of this barrier floodwaters rushed downstream washing away Rishiganga hydropower project upstream of Rini.

7.4 Intermittent Damming around Rini

Rishiganga river meets Dhauliganga river at almost right angles near Rini village at an altitude of 1,960 m asl. The floodwaters of Raunthi Gadhera travelling down the course of Rishiganga river along with huge amount of debris and rock mass hit the valley wall on the right bank of Dhauliganga river deflecting its flow, and causing deposition of debris to block the course of Dhauliganga river for a short duration. The evidences of impoundment of water are observed on the valley walls along the course of Dhauliganga river upto 1 km upstream of its confluence with Rishiganga river, and the level of the impounded water is assessed as being 3-4 m above the normal river level (Figure 7). It is this blockade that added huge volume of water, and its breach resulted in the devastation of downstream areas including the hydropower project at Tapoban.

8. Discussion and Way Forward

The frictional forces and impact of the rock avalanche facilitated melting of ice but it could not have instantaneously produced around 6 million cu m water. The assertion of instantaneous melting of ice is at the same time refuted by large chunks of ice observed in the debris material along the lower slopes of Raunthi Gadhera as also those enbedded in the debris barrier damming the Rishiganga river. Therefore, based on field evidences, the flood event of February 7, 2021 is attributed to sequential intermittent damming along the course of Raunthi Gadhera, Rishiganga, and Dhauliganga rivers.

Absence of warning infrastructure in the catchment resulted in massive loss of human lives as a simple water level recorder based warning system around the hydropower project on Rishiganga river would have averted loss of human lives at Tapoban. The following measures are therefore recommended to avert similar incidences in future.

8.1 Disaster Risk Assessment

It seems that the flood history of Dhauliganga river (Table 2) and evidences of previous damming (Figure 6, and 9) were ignored while planning the hydropower projects. Comprehensive inventory of previous disaster incidences is therefore recommended to establish the hazard profile of the area. Risk assessment should accordingly be undertaken and account for extreme events with long recurrence period. This should be a mandatory legal requirement for all major developmental projects in the Himalayan region. Putting these reports in public domain would either discourage the insurance companies from extending safety cover to the unsafe projects or force them to make premiums economically unviable. This in turn would ensure that only disaster safe projects are implemented in this hazard prone terrain.

8.2 Warning Generation and Dissemination

With present level of technical knowledge, instrumentation, and communication facilities warnings, particularly of hydro-meteorological events, can be easily generated and disseminated. A network of hydro-meteorological observatories with real time data transmission capability should thus be calibrated for this purpose to provide rainfall threshold based flood / flash flood and landslide warnings. Hydropower projects should be mandated to contribute data and resources towards this network.

Streams and rivers are generally dammed at places with favourable geomorphic configuration and these areas can be identified through dedicated geomorphic mapping. Appropriate monitoring infrastructure should be resorted to around these places for prompt mitigation measures in case of damming.

8.3 Diversification

Diversification of assets, though a risk reduction strategy, ensures equitable development of the region. In the present context two hydropower projects were located in close proximity, and both were damaged in the incidence. It is therefore suggested that as a policy measure, major infrastructure not be allowed to be concentrated in a particular area.

At present most investors desist from venturing into remote areas of the province, and are keen to invest in areas that are relatively developed in terms of basic infrastructure and facilities. To start with the state could create basic facilities and infrastructure in identified suitable parts of the state and the same could be an incentive for the investors to explore possibilities of setting up their venture in other areas. As a by-product, this exercise would ensure balanced development of the province.

8.4 Abnormal Meteorological Observations

The present incidence was accompanied by abnormal rise in temperature. It is therefore suggested that abnormal changes in meteorological parameters be taken note of seriously and correlated with possible triggering of some hazard prevalent in the proximity. Precautionary actions can also be initiated based on such observations. This exercise is sure to be futile in most instances but is certainly worth trying, as it could sometimes save human lives.

9. Conclusions

Though not conclusively attributed to climate change abnormal temperature rise contributed to this disaster in one way or the other, while sequential intermittent damming increased the devastating potential of the floodwaters. The possibility of recurrence of similar incidences gaining ground with climate change impacts becoming increasingly prominent, the region is to face scarcity of capital investment which in turn is to have adverse impact on the pace of growth and socio-economic development. With environmental groups already lined up to hold hydropower projects responsible for this disaster, the fate of hydropower as also other major infrastructure projects in the Himalayan region is sure to have long-term adverse implications.

In order to ensure disaster resilient, environment friendly, and holistic development of the region authors recommend (i) scientific documentation of previous catastrophic events, (ii) detailed, focused, and long-term studies for in depth assessment of risk posed by various hazards, with incorporation of climate change driven extreme events, (iii) implementation of a legally binding disaster risk assessment, and reduction regime, (iii) robust, reliable, and redundant warning generation, and dissemination infrastructure, and (v) policy for the diversification of assets.

Acknowledgements

PR and SK(1) thank the officials of USDMA for providing opportunity of field investigations and District Disaster Management Authority (DDMA), Chamoli, State Disaster Response Force (SDRF) and Indo-Tibetan Border Police (ITBP) for logistics support during the field investigations. Colleagues at USDMA are thanked for support, encouragement and suggestions.

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 DOI: https://doi.org/10.30564/jees.v3i2.3069

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Journal of Environmental & Earth Sciences
https://ojs.bilpublishing.com/index.php/jees

ARTICLE

A Comparative Study of Groundwater between Geological Groups of Southern Benue Trough, Nigeria Using Modelling Approach

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ARTICLE INFO

Article history
Received: 6 September 2021
Accepted: 8 October 2021
Published Online: 22 October 2021

Keywords:
Weathering
Ion exchange
Group
Groundwater
Nigeria

ABSTRACT

Groundwater studies were carried out between two geological groups to evaluate factors that influences groundwater geochemistry. To achieve this, 30 groundwater samples were collected. Parameters such as pH, Electrical Conductivity (Ec), Total Dissolved Solids (TDS), Total Hardness (TH), and hydrochemical characteristics (Na^{2+}, K^{+}, Ca^{2+}, Mg^{2+}, HCO_3^{-}, NO_3^{-}, Cl^{-}, CO_2^{3-}, and SO_4^{2-}) of groundwater were determined. Findings revealed that the pH value for Asu River Group ranges from 5.3 to 7.5, and that of Eze Aku Group ranges from 4.1 to 7.9. It was observed that areas around the mines had low pH values. Analyzed results that were obtained were interpreted using various hydrogeochemical models. Parson plots reflected that groundwater within the two geological groups fell within Ca-Mg-SO_4 and Ca-Mg-Cl. Results from End-member plots showed that 96% of groundwater samples analyzed were categorized under carbonate weathering, 4% fell silicate weathering. Gibbs plots revealed that interactions between groundwater and surrounding host rocks are mostly the main processes responsible for chemical characteristics of groundwater, Diamond field plots suggested that groundwater within the study were categorized to be high in Ca + Mg & SO_4 + Cl, the plot of $Ca^{2+}/(HCO_3^{-} + SO_4^{2-})$ against Na+/Cl^{-} revealed that groundwater was considered to be within the natural state for the two group. The plot of TDS against TH showed that groundwater is classified as soft freshwater. The study revealed there was no significant difference between factors that influence groundwater within the two geological.

1. Introduction

Groundwater is preferred to surface water based on the fact that it is readily free from surface contamination, and considered to be less prone to contamination when compared to surface. In most scenarios groundwater is contaminated by infiltration from surface pollution such as leakage from septic tanks, mining activities, indiscriminate waste disposal close to surface water sources, and others. Several factors are for the alteration of the groundwater resource. Groundwater resource is considered to be a major source of water for various users across the world. In the same vein [1] reported that groundwater resources are recognized as an important aspect of freshwater resources and that is required for sustaining ecosystems, natural and human development. Therefore is considered necessary to constantly evaluate its quality and suitability for various uses. Various scholars within the southern Benue Trough

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  DOI: https://doi.org/10.30564/jees.v3i2.3694

of Nigeria have assessment water resources for various uses ranging from irrigation, industrial and domestic use [2-4]. Their findings suggested that groundwater quality and geochemistry are altered by geogenic and anthropogenic activities such as rock-water interaction, weathering, and mining, among others. [5] thought that the geochemistry of groundwater within the Asu River Group of the southern Benue Trough is highly influenced by geogenic activities such as carbonate and silicate weathering and that the movement of groundwater is influenced by factors such as thickness, lithofacies, and the formation process of rock. On the same note [6-8] acknowledge that hydrochemistry of groundwater resources depends on the following; the quality of recharge water, level of chemical weathering of diverse rock types, local or regional of an area, and lastly, human activities. According to [2-5], awareness of hydrogeochemistry is of paramount importance as it plays a major in determining the origin, chemical composition, and characterization of groundwater concerning a particular region or locality. The importance of hydrogeochemistry cannot be underestimated as it has led to several detailed studies on groundwater quality deterioration and geochemical evolution of groundwater in many parts of the globe [9-11]. A detailed study on hydrochemical processes of aquifer system help gives information about the interaction between aquifer system and its surrounding environment and the effect of anthropogenic and geogenic activities on groundwater chemistry. Several factors such as evaporation, precipitation, oxidation-reduction, weathering, sorption, and ion exchange reactions tend to may play a major role in altering the chemical composition of groundwater [12]. [5] pointed out that the reaction between groundwater and aquifer minerals has a major role to play in groundwater quality which is useful to predicate the source of groundwater. It is essential to evaluate the relationships among the chemical parameters and also factors that influence the chemical composition of groundwater. Additionally, recent studies conducted on groundwater quality revealed that groundwater within the Asu River Group fell with two categories temporary and permanent hardness Ca^{2+}- Mg^{2+}- HCO_3^- and Ca^{2+}- Mg^{2+}- Cl^- they attributed groundwater hardness to the presence of calcium and magnesium in water [13]. Lately, studies have been carried out of the hydrogeochemical assessment of groundwater quality within different geological groups of southern Benue Trough, especially around the mines within the southern Benue Trough of the sedimentary basin, but detailed study has not been carried to evaluate factors that influence groundwater within the Asu River Group (ARG) and the Eze Aku Group (EAG) of southern Benue Trough of Nigeria. Two mines exist within the study area; these are the lead-zinc mine at Enyigba and Ameka. The leakage of chemicals from these mines sites, geogenic and anthropogenic activities have influenced the chemical composition of groundwater within the area [2,14]. Hence, a detailed study is necessary to get a piece of baseline information that will in-turn be needed to establish long-term groundwater monitoring programs for sustainable development of groundwater within the study area. This study is aimed at (i) evaluating the geochemical characteristics of groundwater and (ii) investigating factors that influence the groundwater chemistry within the ARG and EAG of southern Benue Trough of Nigeria. It is believed that findings from this study will help monitor factors that influence the hydrochemistry of groundwater and also help in enhancing the groundwater quality.

Geographical, geological, and hydrogeological overview

The study area lies between 6°03′ and 6°15′N and longitudes 8°03′ and 8°15′E as shown in Figure 1. It is located in Ebonyi state, southeastern Nigeria. The study area is accessible via a network of roads. Geologically, the study area lies within the southern part of Benue Trough, which is regarded as a sedimentary succession of pre-Santonian periods that is of the Albian and Turonian times (Table 1). The two major groups that cut across the study area are the Asu River Group (ASG) and Eze Aku Group (EAG), according to [15] the ASG is Albian in age. The Abakaliki and Ebonyi Formation underlie the ASG [16]. [17,18] report that the rock unit that exists within the study area are alternating shales and siltstones with occurrences of fine-grained micaceous and feldspathic sandstone, limestone, and mudstone. [19] reported that the EAG is Turonian in age and it uncomfortably overlies the ARG and that the EAG entails lithostratigraphic sections deposited from the late Cenomanian to Turonian in age. Previous reports according to [20-22] revealed that several factors such as integration of tectonism with magmatism coupled with diagenesis have altered the mineralogical and geochemical constituents of subsurface rock, which trigger there baking making them suitable for construction. Various authors reported the occurrence of lead-zinc (Pb-Zn) [23]; [24] stated that the presence of Pb-Zn minerals within the study area exists in veins as open space-fillers within en echelon, tensional, and steeply dipping fracture systems in the dark-gray to black shales of the Asu River Group also encouraged their rampant excavation. Groundwater (aquifer) within the study area was classified into two aquifers (i).The shallow unconfined (ii). The deep confined aquifer system [25]. Although [26] believed that the shallow unconfined aquifer is

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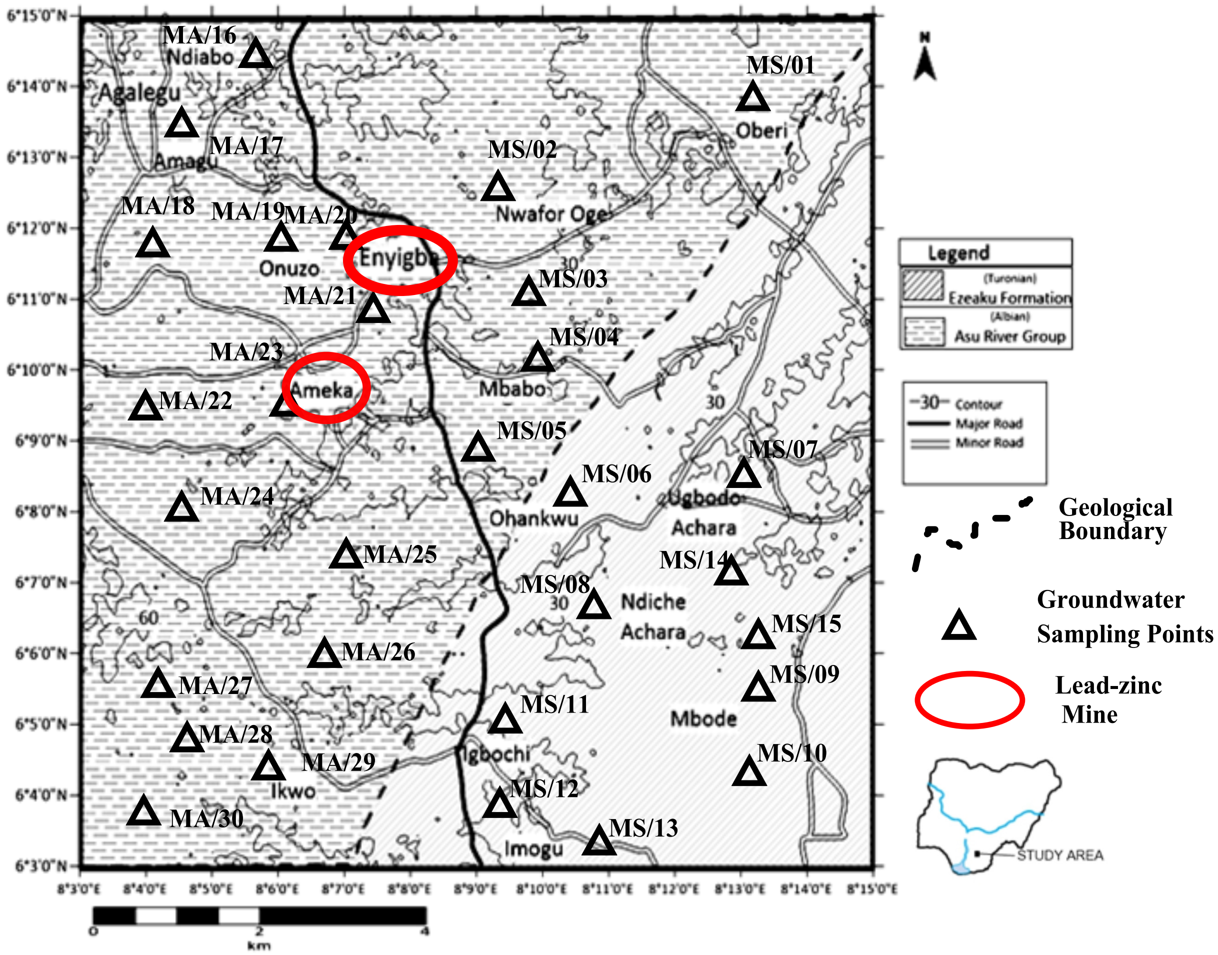

Figure 1. Geology Map of the Study Area Showing Groundwater Sampling Points

said to occur in fractured, weathered, jointed shale and some patched sandstone in the study area. Groundwater movement and storage within the study area are primarily influenced by thickness, lithology, and structure of rock formation.

2. Materials and Methods

For this study, 30 groundwater samples were randomly collected within the study area as shown in Figure 1. Groundwater samples were determined using appropriate titrimetric method as described by [27]. Groundwater samples were collected and filtered and further stored in plastic containers in an icebox with temperatures ranging from 3^0C to 5^0 C and preserved in a refrigerator (<5^0C) after acidification by nitric acid (5 mL of 6 N HNO_3). Certain parameters such as pH, temperature (T), Electric Conductivity (Ec), and Total Dissolved Solids (TDS) were determined in-situ using the HACH conductivity meter. While chemical parameters such as; calcium (Ca^{2+}), magnesium (Mg^{2+})' bicarbonates (HCO_3^-), and chlorides (Cl^-) ions were analyzed by volumetric titrations. Sulfate (SO_4^{2-}) ions were analyzed using a Jenway clinical fame photometer (PFP7 model. Sodium (Na^+), and Potassium (K^+) ions were analyzed by atomic absorption spectrometer Jenway clinical fame photometer PFP7 model in the laboratory.

The cation-anion balance was also assessed using electrical neutrality equation, expressed in meq/L.

$$\% \, difference \left(\frac{meq}{L}\right) = \left(\frac{\sum cations - \sum anions}{\sum cations + \sum anions}\right) \times 100\% \quad (1)$$

Total hardness

Total hardness of the groundwater was calculated using the formula given by [28,29].

$$TH = (Ca^{2+} + Mg^{2+}) \times 100 \quad (2)$$

3. Results and Discussion

Based on the results of the physicochemical analysis for the two geology group with the minimum, maximum, and mean values in meq/L and the statistical parameters are determined, as shown in Table 1.

DOI: https://doi.org/10.30564/jees.v3i2.3694

Table 1. Result of hydrochemical Parameters

Sampling Code	Latitude and Longitude	EC (µS/cm)	pH	TDS	TH (mg/L)	Ca^{2+} (meq/L)	Mg^{2+} (meq/L)	Na^{+} (meq/L)	K^{+} (meq/L)	Cl^{-} (meq/L)	NO_3^{-} (meq/L)	SO_4^{2-} (meq/L)	HCO_3^{-} (meq/L)	CO_2^{3-} (meq/L)
MS/01	$6^0$14′32″-$8^0$14′53″	736	7.3	482	81	0.33	0.48	0.10	0.37	3.19	0.03	3.22	0.03	0.87
MS/02	$6^0$12′56″-$8^0$09′57″	48	6.8	165	91	0.16	0.75	0.03	0.12	2.40	0.00	1.54	0.01	0.75
MS/03	$6^0$11′09″-$8^0$10′41″	191	5.7	592	105	0.47	0.58	0.06	0.29	1.21	0.00	5.07	0.44	1.38
MS/04	$6^0$10′11″-$8^0$10′13″	585	5.5	502	106	0.12	0.94	0.30	0.02	3.03	0.01	4.69	0.13	1.42
MS/05	$6^0$08′55″-$8^0$09′55″	384	6.9	644	124	0.43	0.81	0.05	0.13	2.49	0.01	2.53	0.40	1.84
MS/06	$6^0$08′32″-$8^0$11′43″	294	7.5	843	71	0.32	0.40	0.30	0.28	4.17	0.02	6.46	0.42	0.43
MS/07	$6^0$08′20″-$8^0$13′43″	1084	6.4	211	28	0.25	0.03	0.05	0.39	6.38	0.01	4.67	0.03	0.64
MS/08	$6^0$06′32″-$8^0$10′28″	492	6.6	482	17	0.11	0.06	0.01	0.24	1.30	0.00	1.46	0.23	1.33
MS/09	$6^0$05′22″-$8^0$13′08″	550	6.1	707	98	0.23	0.75	0.03	0.14	2.47	0.00	7.46	0.23	1.88
MS/10	$6^0$04′08″-$8^0$13′43″	495	5.6	229	17	0.14	0.03	0.04	0.58	3.03	0.05	3.66	0.48	0.35
MS/11	$6^0$05′11″-$8^0$09′53″	707	6.4	494	7	0.32	0.38	0.03	0.13	6.28	0.01	2.53	0.23	0.17
MS/12	$6^0$04′36″-$8^0$09′48″	694	5.3	585	7	0.13	0.57	0.01	0.45	5.11	0.02	5.64	0.10	1.56
MS/13	$6^0$03′32″-$8^0$11′27″	94.4	7.4	647	31	0.24	0.07	0.01	0.27	6.35	0.00	7.03	0.30	1.84
MS/14	$6^0$07′18″-$8^0$13′27″	308	6.1	192	65	0.33	0.32	0.04	0.11	7.44	0.00	8.43	0.00	1.66
MS/15	$6^0$06′47″-$8^0$13′36″	411	5.6	854	75	0.17	0.58	0.03	0.32	4.03	0.00	3.08	0.23	1.36
MA/16	$6^0$14′55″-$8^0$04′28″	996	6.5	290	4	0.20	0.20	0.02	0.48	3.04	0.03	4.74	0.20	0.58
MA/17	$6^0$13′44″-$8^0$05′45″	495	7.3	308	104	0.46	0.58	0.04	0.12	5.69	0.00	6.30	0.17	1.75
MA/18	$6^0$11′53″-$8^0$04′51″	184	6.5	404	96	0.92	0.04	0.01	0.26	7.31	0.00	6.05	0.04	1.05
MA/19	$6^0$11′57″-$8^0$06′15″	794	6.0	553	92	0.72	0.20	0.02	0.49	4.60	0.01	2.53	0.30	1.13
MA/20	$6^0$11′15″-$8^0$07′30″	839	4.1	347	112	0.61	0.51	0.07	0.07	2.91	0.02	1.60	0.43	1.49

Sampling Code	Latitude and Longitude	EC (µS/cm)	pH	TDS	TH (mg/L)	Ca^{2+} (meq/L)	Mg^{2+} (meq/L)	Na^{+} (meq/L)	K^{+} (meq/L)	Cl^{-} (meq/L)	NO_3^{-} (meq/L)	SO_4^{2-} (meq/L)	HCO_3^{-} (meq/L)	CO_2^{3-} (meq/L)
MA/21	6^{0}10⁄51⁄⁄-8^{0}07⁄09⁄⁄	1173	4.4	575	125	0.82	0.43	0.09	0.21	5.32	0.00	2.33	0.15	1.07
MA/22	6^{0}09⁄25⁄⁄-8^{0}04⁄03⁄⁄	1083	4.1	854	111	0.94	0.17	0.04	0.20	6.00	0.05	4.65	0.27	1.39
MA/23	6^{0}10⁄12⁄⁄-8^{0}06⁄44⁄⁄	861	4.9	543	64	0.31	0.33	0.03	0.38	2.39	0.02	6.30	0.82	1.04
MA/24	6^{0}08⁄39⁄⁄-8^{0}04⁄23⁄⁄	619	4.4	354	115	0.54	0.61	0.08	0.12	4.24	0.01	9.02	0.53	1.33
MA/25	6^{0}07⁄02⁄⁄-8^{0}07⁄21⁄⁄	599	7.3	544	85	0.48	0.37	0.01	0.22	1.04	0.01	1.53	0.08	1.50
MA/26	6^{0}05⁄44⁄⁄-8^{0}06⁄53⁄⁄	408	7.0	967	97	0.92	0.05	0.01	0.11	4.47	0.00	4.57	0.01	1.42
MA/27	6^{0}05⁄54⁄⁄-8^{0}04⁄13⁄⁄	814	7.9	588	74	0.72	0.02	0.11	0.42	0.26	0.00	2.35	0.05	0.53
MA/28	6^{0}04⁄47⁄⁄-8^{0}04⁄38⁄⁄	69.3	5.7	865	76	0.52	0.24	0.20	0.11	2.74	0.00	1.43	0.04	0.99
MS/29	6^{0}04⁄31⁄⁄-8^{0}06⁄35⁄⁄	50.1	7.5	678	104	0.93	0.11	0.03	0.39	5.57	0.00	2.45	0.03	1.53
MS/30	6^{0}03⁄36⁄⁄-8^{0}03⁄58⁄⁄	274	6.0	575	142	0.99	0.43	0.05	0.32	6.33	0.03	5.75	0.02	1.51
Minimum	N/V	48	4.4	165	4	0.11	0.02	0.01	0.02	0.26	0.00	1.43	0.00	0.17
Maximum	N/V	1173	7.9	967	142	0.99	0.94	0.3	0.58	7.44	0.05	9.02	0.82	1.88
Average	N/V	548.5	6.40	537.6	77.18	0.46	0.37	0.06	0.26	4.01	0.01	4.36	0.22	1.18

Where= MS is sampling code for groundwater from ARG, MS is sampling code for groundwater from EAG, N/V= No value

Hydrochemistry Evaluation of Groundwater

Electrical Conductivity (Ec)

According to [30], Ec is considered one of the major parameters that are used to determine the suitability of groundwater for use. For this study, the value of Ec ranges from 48 to 1173 µS/cm, with an average value of 548.52 µS/cm. The highest value of Ec was at sample location MS/21 within the EAG axis of the study area as shown in Table 2. This can be attributed to the presence of dissolved ions. Based on Ec obtained, groundwater is considered to be fresh except for sample locations MS/07, MA/21, and MA/22 that were slightly above 1000 µS/cm which were considered saline in nature. Based on the EC, the groundwater of the study area is fresh (< 1000 µS/cm) and only three samples are slightly saline (> 1000 µS/cm).

pH

On a general note, pH determines the acidity or alkalinity of a solution [31]. The result from Table 1revealed that measured pH within the ARG ranges from 5.3 to 7.5 with a mean value of 6.34, hence it's classified to be slightly acidic to basic. 99% of groundwater within the ARG was classified to be acidic except for sample location MS/01, 06, and 13 which was classified to be basic as shown in Figure 2a. while the pH of sampled groundwater within the EAC ranges from 4.4 to 7.9 with the mean value of 6.46, hence groundwater was said to be classified to be slightly acidic to basic as shown in Figure 2b. From Figure 2a and 2b, it was observed that the value of pH around the mine site tends to low when compared to other parts of the study area. That implies that groundwater within the mine is considered to

DOI: https://doi.org/10.30564/jees.v3i2.3694

highly acidic, this was observed around the Enyigba and Ameka mine as shown in Figure 2b. The acidic nature of groundwater around the mine sites can be attributed to the active chemical reactions ongoing around the mine sites, this results in mine water from the active mine site flowing into adjoining streams and river channels while the other water infiltrates into the ground thereby polluting groundwater and making it unsafe for various use [32].

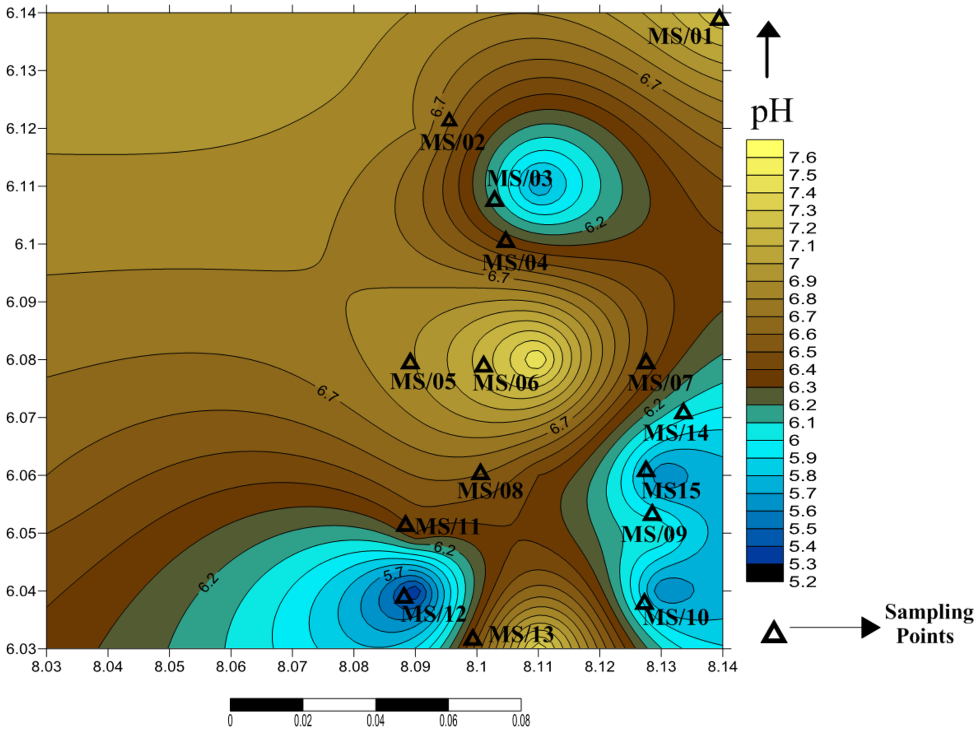

Figure 2a. Spatial Distribution of pH in groundwater within ARG axis of the study area.

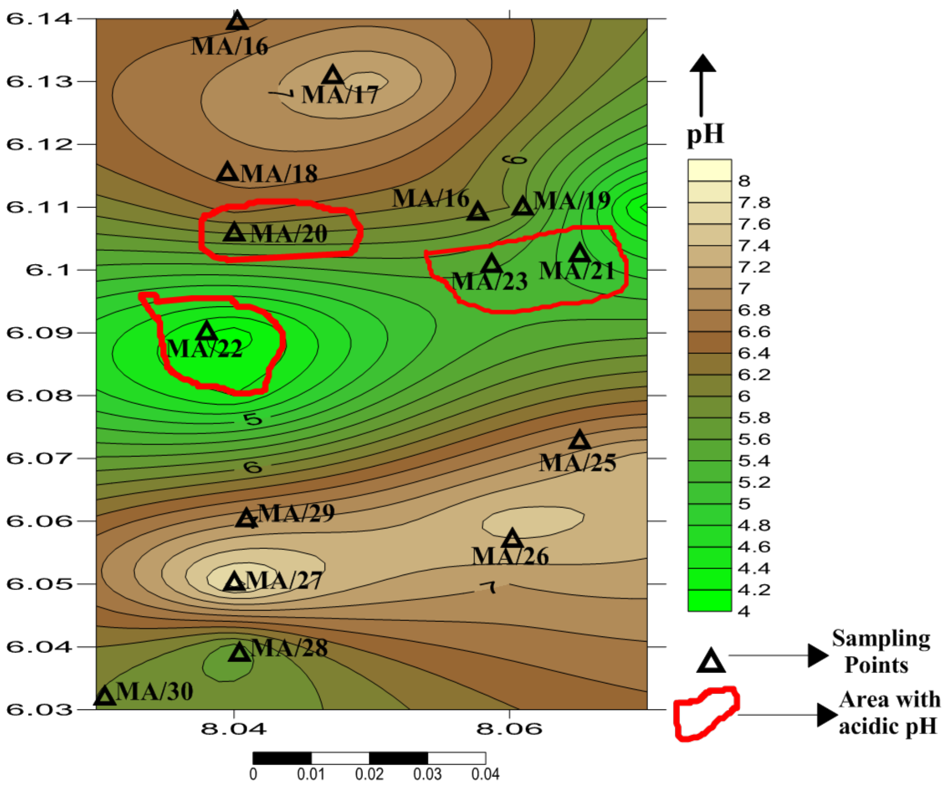

Figure 2b. Spatial Distribution of pH in groundwater within EAG axis of the study area.

Hydrochemical facies

Report according to [5] revealed that hydrochemical facies helps define groundwater in aquifer system and their diverse chemical composition. Further studies conducted by [33] revealed that facies is the function of lithology solution kinetics and flow pathway of their aquifer. They further pointed out that it is complex to interpret a huge table of analytical data as regards water quality. For a better interpretation of water resources, data models and graphs are mostly used for its interpretation and better understanding. Most study models are more preferable and are easily used to characterize water resources. Models used for this study include Parson, End-Member, Gibbs plots, reconstructed Diamond field, the plot of TDS against TH among others.

Parson Plot

The water classification of hydrogeochemical facies of Piper diagram was reconstructed by Lawrence and Balasubramanian, in the new reconstructed diamond field. A Parson plot classified that groundwater samples were classified in two categories Ca-Mg-SO_4 and Ca-Mg-Cl water type see Figure 3a and 3b. From Figure 3a Groundwater samples it was observed that samples MS/01, 03, 04, 05, 06, 08, 09, 10, 12,13, and 14 fell within Ca-Mg-SO_4 water type, while MS/02, 11, 07, and 15 fell within Ca-Mg-Cl water type such water type is classified to permanently hard water. Similar study conducted by [14] within the southern Benue trough, Nigeria reported that groundwater within the Asu River Group is permanently hard, this may be due to the fact that host rock weather and eventually residence over time in groundwater thereby altering the geochemistry of groundwater. From Figure 3b, it was observed sample location MA/16, 17, 24, 25, 26, and 27 was classified to be of Ca-Mg-Cl water type, and samples MA/18, 19, 20, 21, 22, 23, 28, 29, and 30, Similar studies done in Enyigba and Umuoghara mining of Ebonyi state, Nigeria [5,14] revealed groundwater within that terrain is classified to be hard due to rock water interaction.

End- Member Plot

The End-member plot is used to analyze the hydrogeochemistry of groundwater and rock weathering that influence groundwater. [35] first proposed an End-member plot using the ratio of Ca^{2+}/Na^+ versus Mg^{2+}/Na^+ and HCO_3^-/Na^+. For this present study, the ratios of Ca^{2+}/Na^+, Mg^{2+}/Na^+, and HCO_3^-/Na^+ ranges from 0.4 to 92, 0.18 to 57, and 0.00 to 27.33, respectively. Findings revealed that 96% of groundwater is majorly influenced by carbonate weathering, suggesting that the weathering of carbonate is a major hydrogeochemical process controlling groundwater hydrochemistry, 4% is influenced by silicate (Figure 4a and 4b).

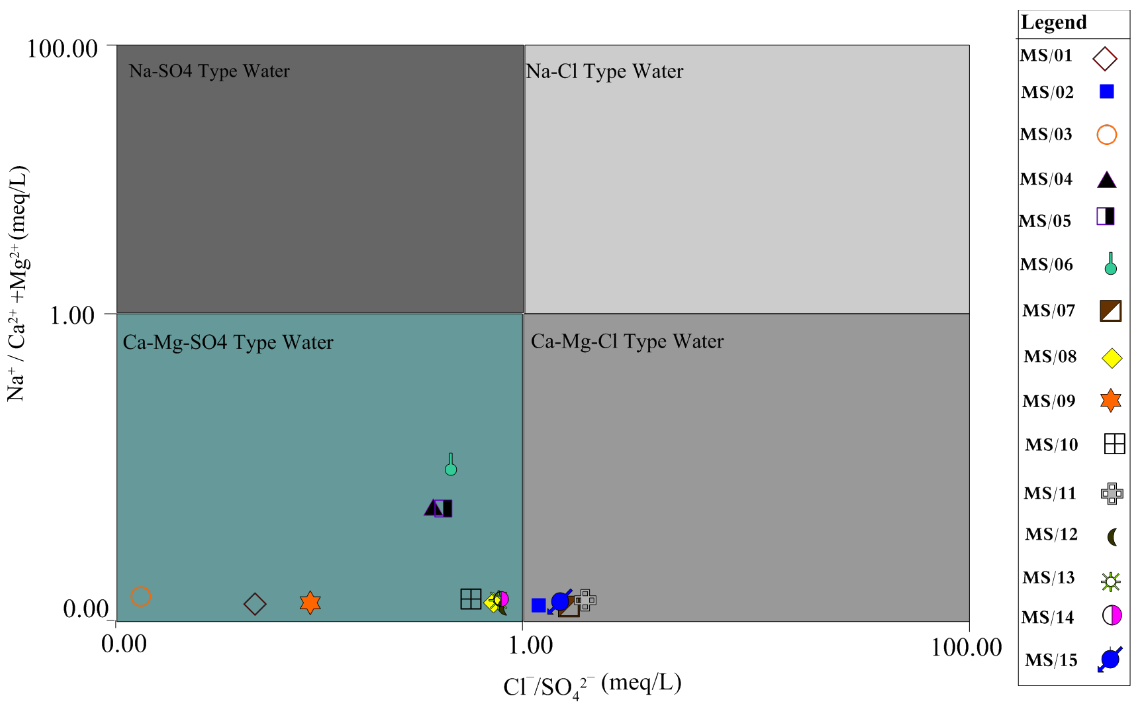

Figure 3a. Parson's Plot Modified after, [34] of the study area showing ground water origin within ARG axis of the study area.

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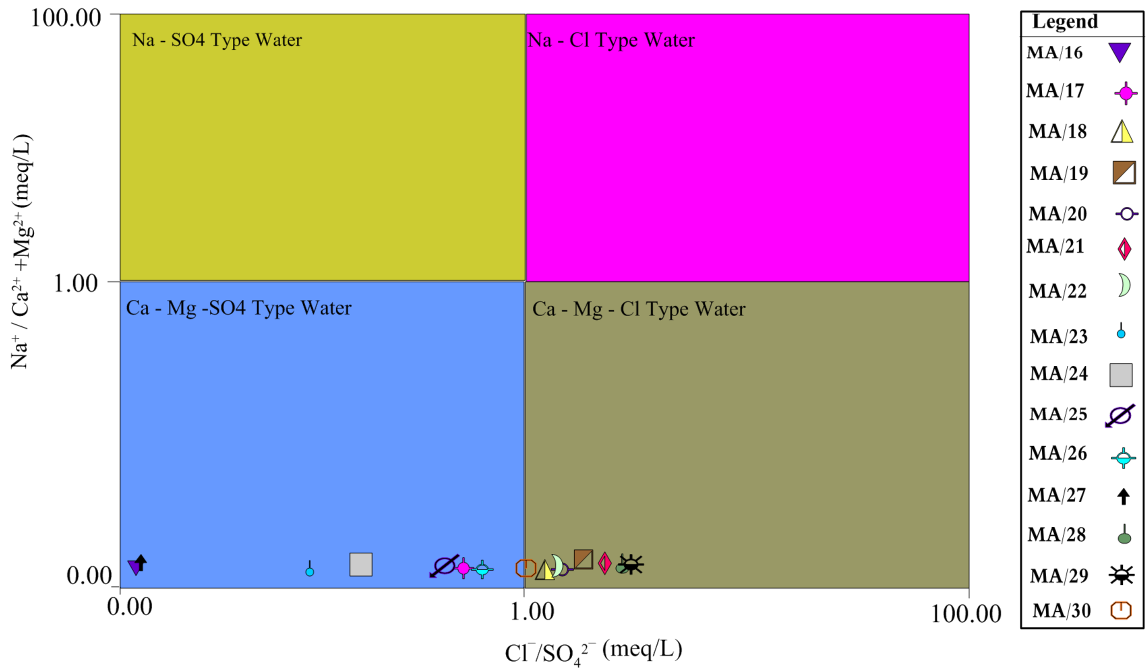

Figure 3b. Parson's Plot Modified after, [34] of the study area showing ground water origin within EAG axis of the study area.

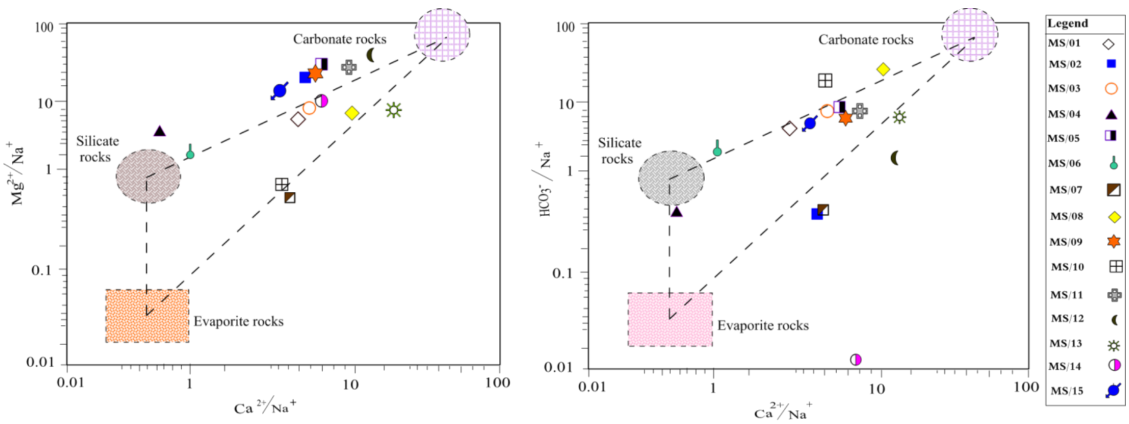

Figure 4a. End-member plot for groundwater samples within ARG axis of the study area.

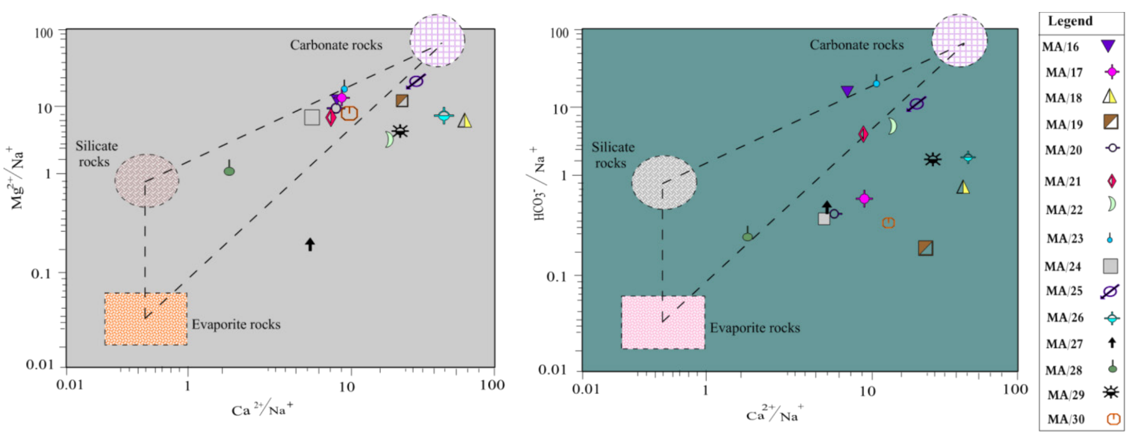

Figure 4b. End-member plot for groundwater samples within EAG axis of the study area.

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Gibbs Plot

Gibbs plot is a plot of log (TDS) against ratios of $Na^+/(Na^+ + Ca^{2+})$ and $Cl^-/(Cl^- + HCO_3^-)$, are widely used to assess the distinction between waters controlled by water-rock interaction (i.e. weathering, leaching, and dissolution), evaporation and precipitation [36]. The plot is used to interpret the main factor(s) that influence groundwater geochemistry. From Figure 5a and Figure 5b, it was observed that the major factor that influences groundwater is the rock weathering process. The result obtained is in line with previous research conducted by [5] which stated that groundwater within the study is influenced by rock water interaction.

The reconstructed Diamond field plot was used to classify groundwater within the study area (Figure 6a and 6b). Its classification is based on reaction within the aquifer system. Results obtained from the model revealed that groundwater collected from ARG and EAG fell within high Ca + Mg + SO_4 + Cl hydrogeochemical facies as shown in Figure 6a and 6b. The previous study within the study area revealed that groundwater was classified as moderately hard [2], the presence of Ca and Mg ions, is the primary cause of hardness in groundwater within the study area. On general note water with high Ca+Mg is said to be hard.

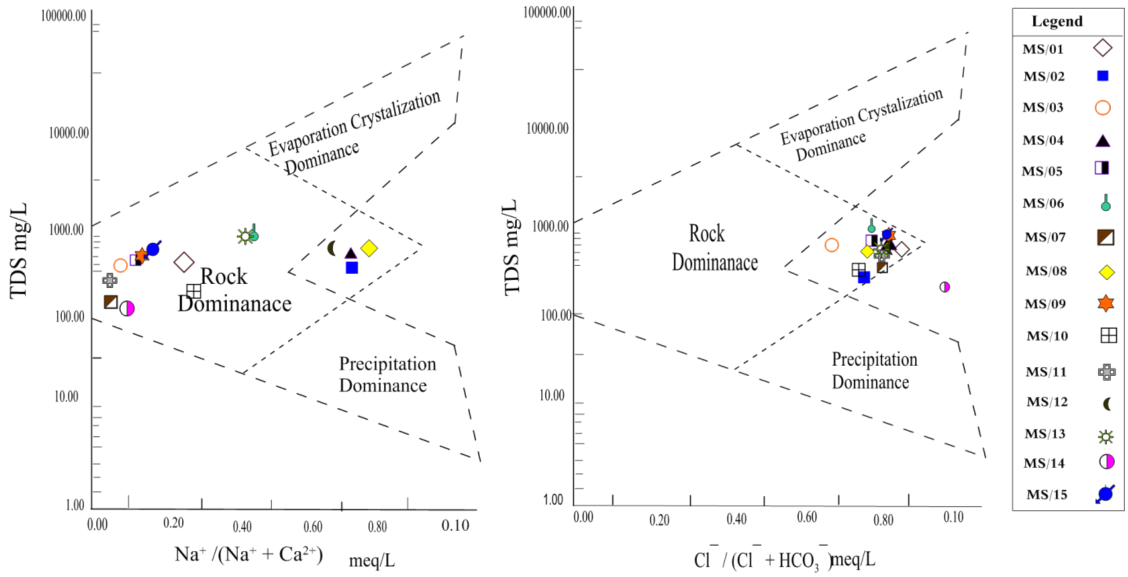

Figure 5a. Gibbs Plot of groundwater collected from ARG axis of the study area.

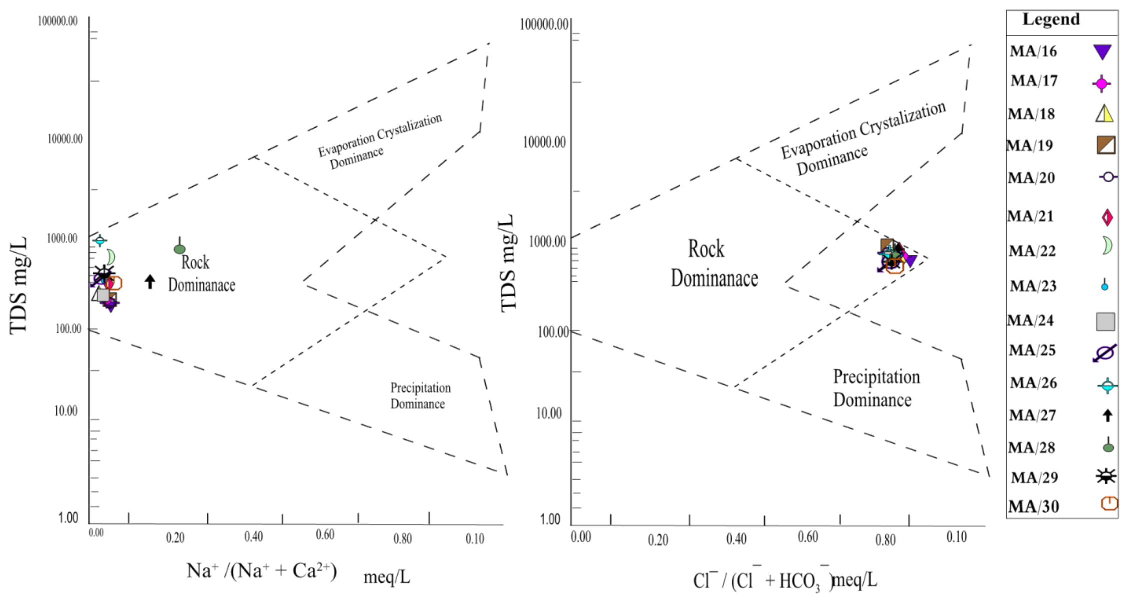

Figure 5b. Gibbs Plot of groundwater collected from EAG axis of the study area.

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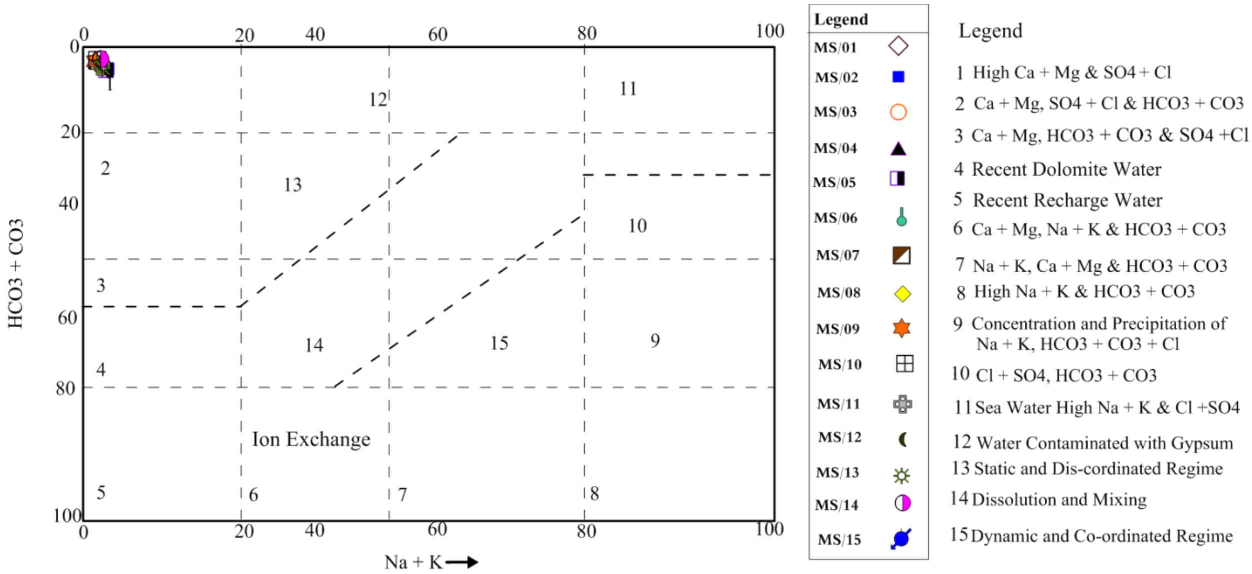

Figure 6a. Classification of Hydrogeochemical Facies reconstructed Diamond field of Piper by [37] of groundwater from ARG axis of the study area.

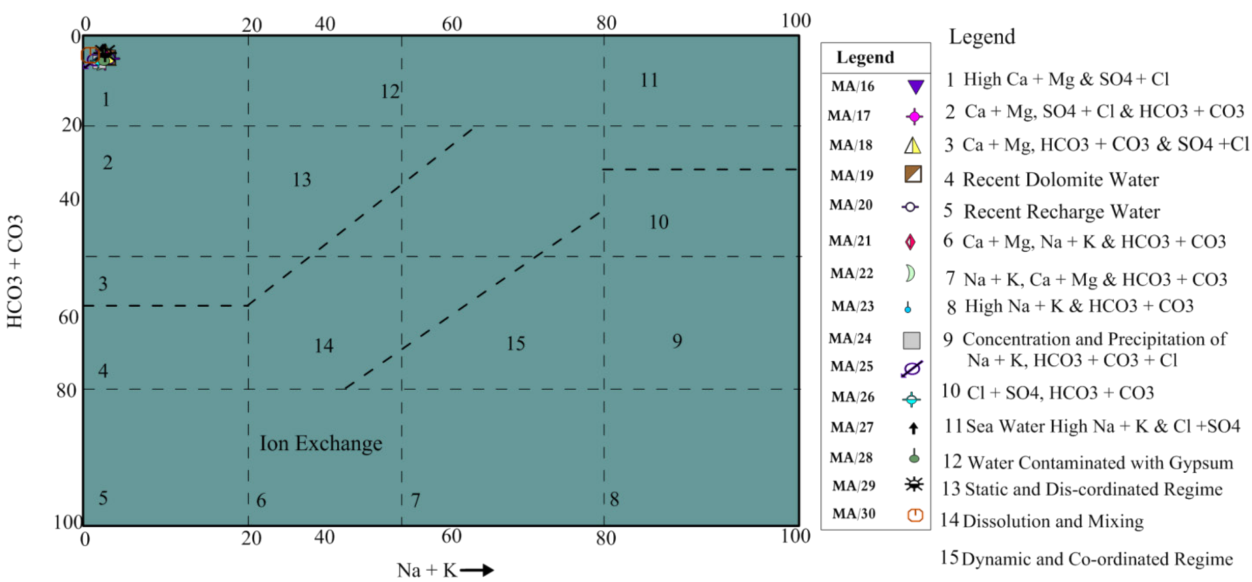

Figure 6b. Classification of Hydrogeochemical Facies reconstructed Diamond field of Piper by [37] of groundwater from EAG Axis of the study area

For a better understanding of the exchange of ions $Ca^{2+}/(HCO_3^{-} + SO_4^{2-})$ was plotted against Na^{+}/Cl^{-}. Figures 7a and 7b showed that sampling points were categorized under natural state, results from Figure 7a and 7b revealed that natural salt dissolution such as carbonates rock, and silicate is the main processes controlling groundwater chemistry within the study area, this is in line with previous studies by [2].

[1] pointed out that TDS and TH are two major important parameters reflecting the quality of groundwater In this study. The value of TH within the Asu River Group ranges from 7 to 124 mg/L with a mean value of 62 mg/L. The results obtained indicate that groundwater was categorized as soft fresh category, this could be attributed to low concentration of Ca and Mg ions found in groundwater samples as shown in Table 1 and Figure 8a. This is in line with previous research carried out by [2]. The value of groundwater within the EAG of the study area ranges from 4 to 142 mg/L with a mean value of 91 mg/L, findings revealed that groundwater fell within soft freshwater category as shown in Figure 8b.

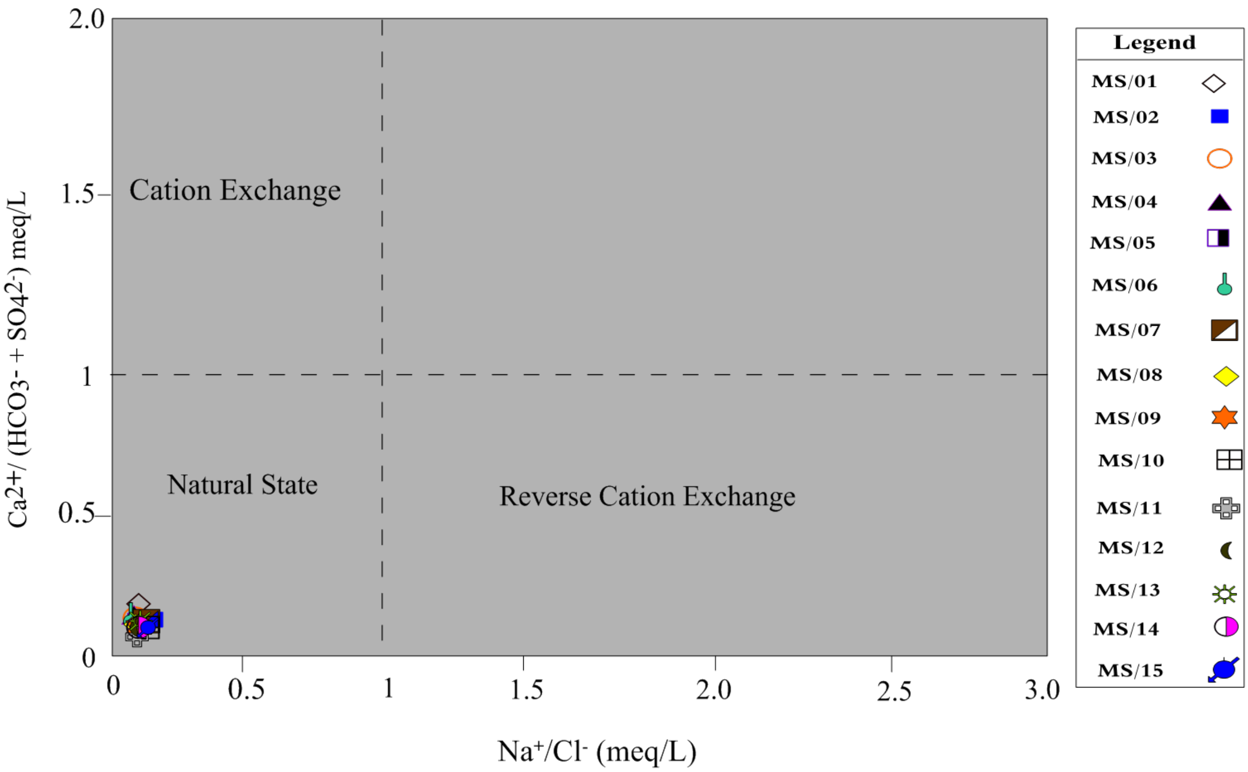

Figure 7a. Showing the effect of cation exchange, reverse cation exchange, natural state, carbonate rock dissolution and silicate hydrolysis on groundwater composition within ARG

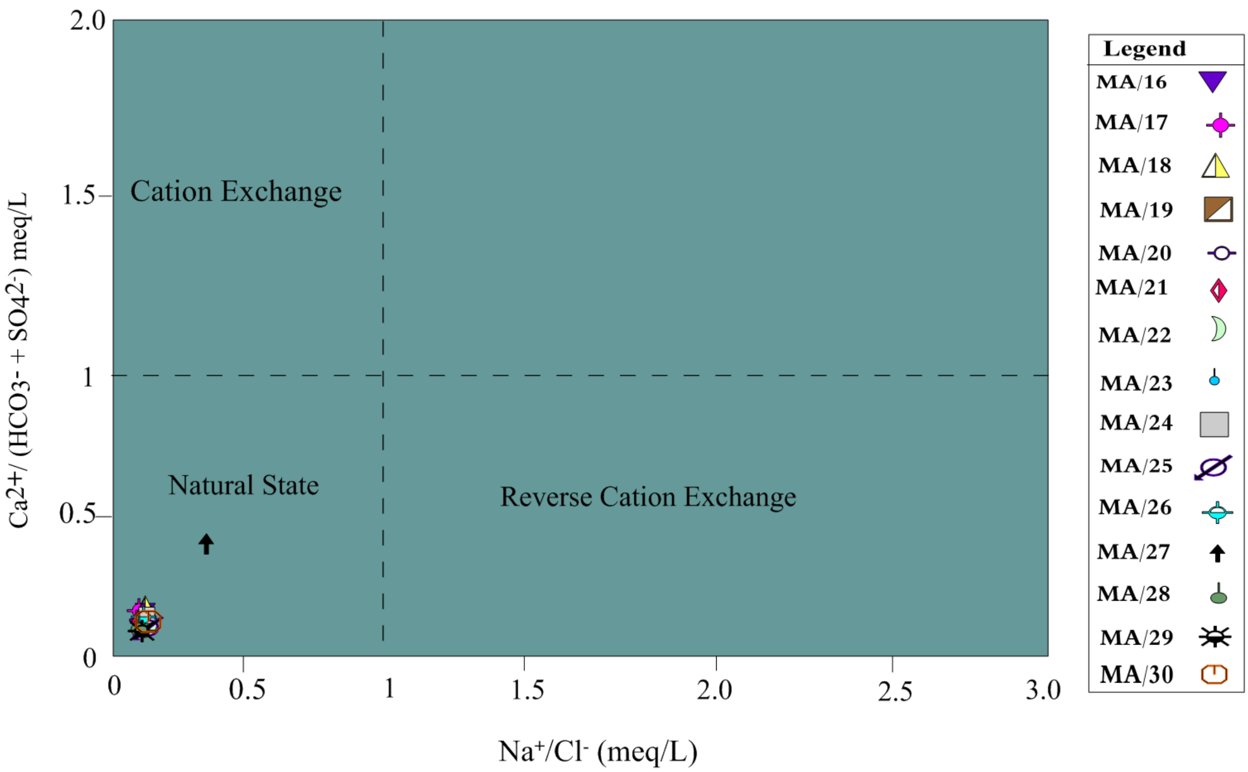

Figure 7b. Showing the effect of cation exchange, reverse cation exchange, natural state, carbonate rock dissolution and silicate Hydrolysis on groundwater composition within EAG.

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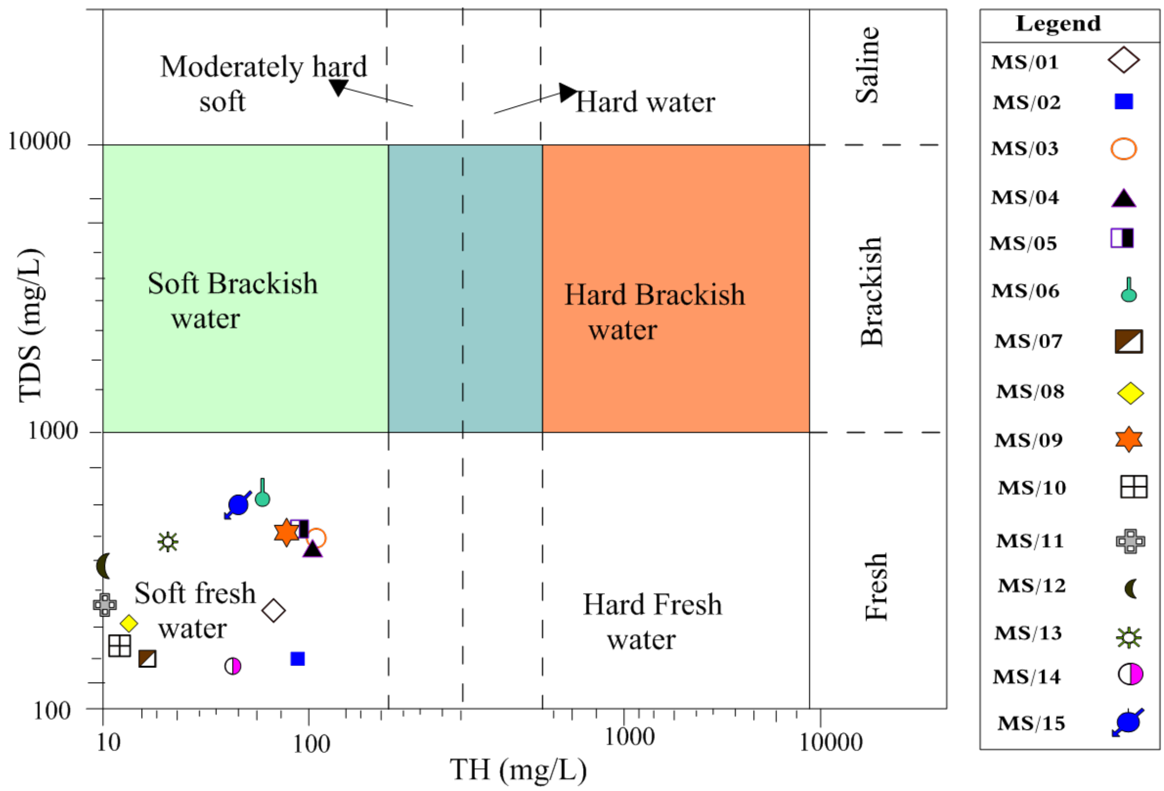

Figure 8a. Plot of TDS versus TH for groundwater samples collected from the ARG that is Albian in age.

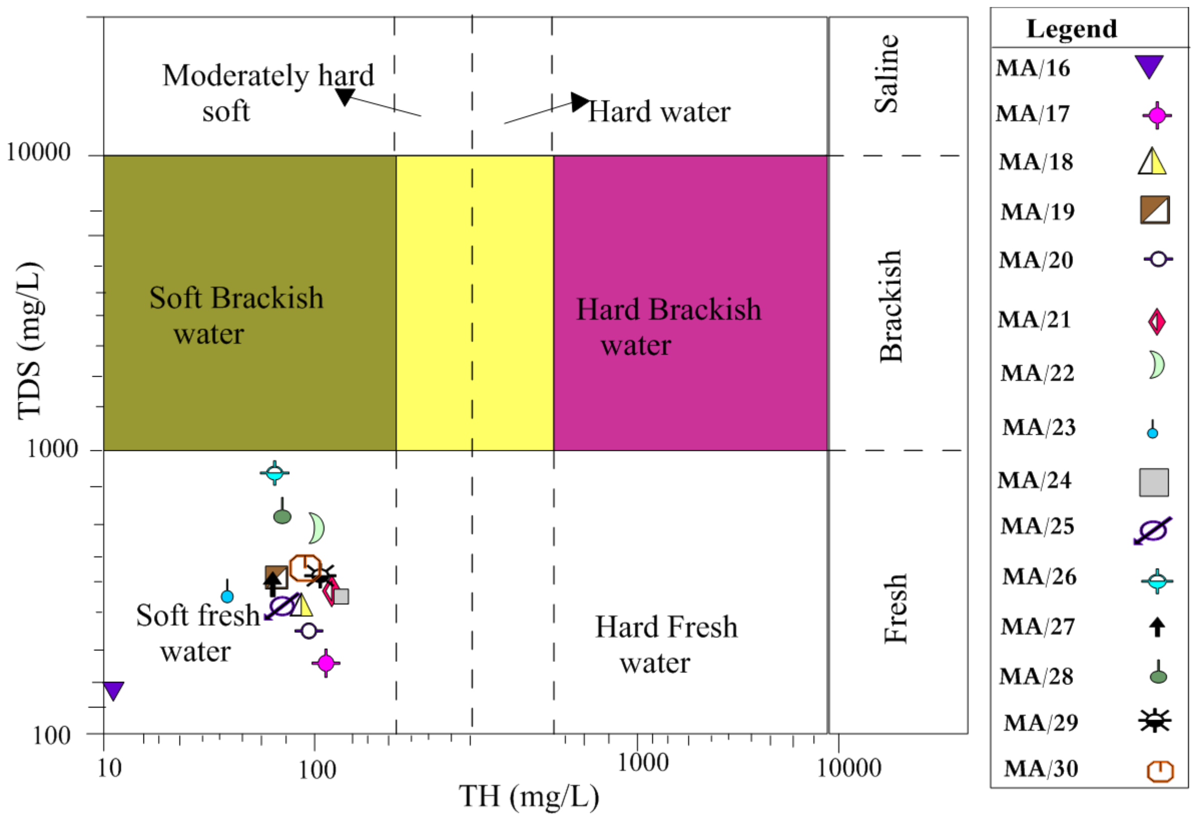

Figure 8b. Plot of TDS versus TH for groundwater samples collected from the EAG that is of Turonian in age.

 DOI: https://doi.org/10.30564/jees.v3i2.3694

4. Conclusions

The present study was to evaluate the possible difference between factors that influences the hydrochemistry of groundwater between the ARG and EAG of the sedimentary basin of Nigeria. Hydrochemical data of groundwater samples were collected from the aquifer within the study area. From studies carried, it was observed that sampling points close to mine (MA/20, 21, 22, 23, and 24) had low pH values indicating that groundwater around those mines area was considered acidic. Results from model use in evaluating groundwater revealed that End-member plots suggested that 96% of groundwater is influenced by carbonate weathering, 4% fell within silicate weathering. The diamond field plot suggested that groundwater was categorized to be high Ca+ Mg +SO_4+Cl hydrogeochemical facies. Gibbs's plots revealed that the major ion composition of the groundwater of the study area is influenced by the composition of the contiguous lithology and reflects rock dominance in its composition. Plots of TDS against TH reveals that groundwater within the study area is considered fresh. The aquifer material/mineralogy together with anthropogenic activities with geogenic factors played a major role in controlling groundwater quality within the two geological groups. Conclusively, it was observed that there were no major differences between factors that influence groundwater within the two geological groups, This could be attributed to the fact that the ARG and EAG of the study area lie within the same sedimentary basin of the southern Benue Trough, but different in age formation.

Conflict of Interest

The authors dare no conflicting interests.

Acknowledgment

The first author Dr. Moses Oghenenyoreme Eyankware is grateful to Professor A.O.I. Selemo for his encouragements and mentorship.

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DOI: https://doi.org/10.30564/jees.v3i2.3694

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ISSN 2661-3190