Editor-in-Chief

Prof. Shuanggen Jin
Nanjing University of Information Science and Technology, China

Editorial Board Members

Sady Mazzioni, Brazil
Maria Barbara Żygadlo, Poland
Sandra Ricart, Spain
Halil Ibrahim Uzun, Turkey
Arun Kumar Vishwakarma, India
Ramayah Thurasamy, Malaysia
Abdeltif Amrane, France
Gholam Khayati, Iran
Prakash Periakaruppan, India
Iféanyichukwu Clinton Ezekwe, Nigeria
Bahram Malekmohammadi, Iran
Remember Samu, Australia
Mehdi Moazzami Goudarzi, Iran
Oihana Gordobil Goñi, Spain
Reza Mohebian, Iran
Dillip Kumar Swain, India
Junfeng Wang, China
Bing-Qi Zhu, China
YanHong Gao, China
Yu Jiang, China
Sunday Ojochogwu Idakwo, Nigeria
Jinya Tian, China
Suvendu Roy, India
Wei Ju, China
Sameh Abd El-Hamid Awwad, Egypt
Isidro A. Pérez, Spain
John Peter A, India
Gokhan OZDAMAR, Netherlands
Shaoyong Lu, China
Souhila AIT HAMOUDI, Algeria
Thyara Campos Martins Nonato, Brazil
Masoud Masoudi, Iran
Rossana Sanfilippo, Italy
Astrida Miceikiene, Lithuania
Huibing Xie, China
Yazan Mohammad Taamneh, Jordan
Xugang Dang, China
Professor Ehsan H. Feroz, United States
Mahmoud Taghavi, Iran
Meng Gao, China
Bing Xu, China
Shaoliang Zhang, China
Fan Yang, China
Mabrouk Sami Mohamed Hassan, Egypt
Corina Michaela Radulescu, Romania
Eugen Rusu, Romania
Contents

ARTICLE

1  Assessment of the Protective Capacity of Vadoze Zone over Aquifer Systems Using Secondary Geoelectrical Parameters: A Case Study of Kaltungo Area North East, Nigeria
   E.Y. Mbiimbe  I.B. Goni  J.M. El-Nafaty  A.U. Yuguda

12  Morphologic Response of a River Channel to Sand Mining in River Tyaa, Kitui County, Kenya
   Philip Gathogo Muiruri  Joy A. Obando  Ishmail O. Mahiri

19  Influence of Temperature and Relative Humidity on Air Pollution in Addis Ababa, Ethiopia
   Mulu Fikeraddis  Lake Endeshaw

26  The Environmental Impact of Plastic Waste
   Boyu Jiang  Jiming Yu  Yihang Liu

36  Sustainability Assessment of the Groundwater Quality in the Khoyrasole Block, Birbhum District, West Bengal to Achieve Rural Water Security
   S. K. Nag  Shreya Das

REVIEW

47  Achievable Sustainable Use and Management of Water Resources for Irrigation in Nigeria
   Moses Oghenyempre Eyankware  Ezekiel Obinna Igwe  Christopher Ogwah
   Ruth Oghenerukevwe Eyankware Ulakpa

56  Methane and Hydrogen Storage in Metal Organic Frameworks: A Mini Review
   Oghenegare Emmanuel Eyankware  Idaeresoari Harriet Ateke

Copyright

Journal of Environmental & Earth Sciences is licensed under a Creative Commons-Non-Commercial 4.0 International Copyright (CC BY-NC4.0). Readers shall have the right to copy and distribute articles in this journal in any form in any medium, and may also modify, convert or create on the basis of articles. In sharing and using articles in this journal, the user must indicate the author and source, and mark the changes made in articles. Copyright © BILINGUAL PUBLISHING CO. All Rights Reserved.
ARTICLE
Assessment of the Protective Capacity of Vadoze Zone over Aquifer Systems Using Secondary Geoelectrical Parameters: A Case Study of Kaltungo Area North East, Nigeria

E.Y. Mbiimbe1* I.B. Goni2 J.M. El-Nafaty2 A.U. Yuguda1
1. Department of Geology, Gombe State University
2. Department of Geology, University of Maiduguri

ARTICLE INFO

Article history
Received: 7 January 2020
Accepted: 14 January 2020
Published Online: 31 August 2020

Keywords:
Assessment
Protective Capacity
Vadose zone
Aquifer systems
Secondary Geoelectric Parameters and Kaltungo Area

ABSTRACT
An assessment of the protective capacity of the vadose zone overlying the aquifer systems in the Kaltungo area was carried out to determine its influence on groundwater quality. Applying the schlumberger array with a maximum electrode spread AB/2 = 100m through VES, thirty water well points were surveyed using Omega terrameter (PIOSO1) resistivity meter. The field data was first subjected to manual interpretation through curve marching and then digitized modeled curves using computer software. The interpreted data revealed that the area is characterized by eleven different curve types representing three to five geo electrical layers. In order to assess the protective capacity of the vadoze zone over the aquifer systems, the longitudinal conductance (S) and transverse resistance (T) (secondary geoelectric parameters) were computed from the primary data using the Dar Zarouk formula. The values of S obtained range from 0.0018 to 0.4056 ohms with a mean value of 0.0135 ohms while the values of T range from 0.55 ohms to 1195.68 ohms with a mean value of 39.84 ohms. The values of S and T obtained reveal that 90% of probed points has poor protective capacity, 10 % has moderate protective capacity and 83 % has high transmissivity, 17 % has intermediate transmissivity. The T and S values are skewed towards poorly protective capacity thus making groundwater in the area highly vulnerable to contamination from the surface. To achieve good groundwater quality in the area, proper completion of newly constructed wells should install protective casing through the entire vadose zone.

1. Introduction
Groundwater remains the most readily available alternative source of supply to humanity especially in areas with limited access to surface water. Aquifer systems in geological complex terrain like crystalline basement vary in nature and extent depending on the bed rock and its degree of weathering. The quality of water from such aquifer systems is determined by a number of factors such as the thickness and composition of the materials in the overburden (vadoze zone), the depth of occurrence and the nature of human activities in the area. An effective groundwater protection is given by protective layers of the vadoze zone with sufficient thickness and

*Corresponding Author:
E.Y. Mbiimbe,
Department of Geology, Gombe State University;
Email: edwinyenika2016@gmail.com
low hydraulic conductivity \cite{18,26}.

Surface geophysical measurements provide an alternative approach for estimation of some of the aquifer properties \cite{2}. In the past 3 decades several investigators have studied the relations between aquifer parameters and geoelectric properties \cite{4,10,13,16,19,23,24}.

In this study 30 VES were conducted at preselected stations employing Schlumberger array. The points were selected based on their proximity to existing production wells with the aim of assessing the protective capacity of the vadose zone to the underlying aquifers systems. The background to this study was conceived from the fact that variations in resistivity of subsurface materials is due to variation in the geology and their characteristic compositions. Transverse resistance (T) and longitudinal conductance (S) (Dar Zarouk Parameters) of the vadose zone for the study area were computed from measured field resistivity data and used to assess the protective capacity of the vadose zone over the aquifer systems.

**Geology of the Study Area**

The study area is part of the Gombe sub-basin of the upper Benue Trough and is geographically located between latitude 9°45’ and 9°50’N, Longitude11°15’ and 11°20’E. The geology of the area is characterized by crystalline basement rocks mainly coarse porphyritic granite, medium grain granite and biotite granite as well as the intrusion of pegmatite and basalt. The sedimentary succession is defined by Cretaceous sediments of the Bima sandstone. (Figure 1). Comprehensive geology of this sub-basin has been discussed in the works of Benkhelil et al \cite{5}, Zaborski et al \cite{27}, Mboringong et al \cite{17}.

**2. Materials and Methods**

**2.1 Theoretical Basis**

An effective groundwater protection is given by protective layers (vadose zone) with sufficient thickness and low hydraulic conductivity leading to longer residence time of percolating water \cite{19}. Residence time of percolating water into the aquifer through materials with large pore spaces is shorter than that for smaller pore spaces and as a result water moves faster leading to poor natural filtration process.

**2.2 Data Acquisition and Processing**

The data for this study is of two sets; the field data (primary) and the processed data (secondary geoelectric data). The primary data was generated in the field from investigating thirty probe points using OhmegaTerrameter employing Schlumberger electrode configuration with a maximum spread of 200 m at (AB/2 = 100m). The field data generated in form of apparent resistivity versus electrode spread was interpreted using WINRESIST computer software to give layer resistivity and thickness for each VES point. The interpreted VES results (layer resistivity values and thicknesses) were used to compute the secondary geo-electric parameters, also known as Dar-Zarrouk parameters. These parameters include the Longitudinal Unit Conductance (S) and Transverse Unit Resistance (T).

**2.3 Longitudinal Conductance**

The longitudinal conductance (S) is the geo-electric parameter used to define target areas of groundwater potential.

\[
S = \frac{h}{\rho a}
\]

Where S is the longitudinal conductance, h is thickness.
and \( \rho_a \) is apparent resistivity of the aquiferous layer. For the purpose of this study the resistivity values of the layers overlying the perceived aquiferous zone was used to compute the \( S \) values (table 4).

### 2.4 Transverse Resistance

The transverse resistance \( (T) \) is one of the parameters used to define target areas of good groundwater potential. It has a direct relation with transmissivity and the highest \( T \) values reflect most likely the highest transmissivity values of the aquifers or aquiferous zones. The transverse resistance \( (T) \) is correlated with aquifer transmissivity to establish the functional relationship of the vadose zone and the underlying aquifer in terms of hydraulic communication. This parameter has been used in this study to evaluate the capacity of the top soil (vadose zone) overlying the aquifer system so as to determine its ability to allow infiltrating water to the aquifer. The assumption is that when geologic materials have high transmissivity, the tendency is for them to permit high infiltration into the underlying aquifer systems. The values of \( T \) for each VES points were computed using the formula below.

\[
T = h \cdot \rho_a
\]  

(2)

Where \( T \) is the transverse resistance, \( h \) is thickness and \( \rho_a \) is apparent resistivity of the aquiferous layer.

### 2.5 Vadoze Zone Protective Capacity

Vadoze zone protective capacity (VZPC) is the capacity of the overburden unit to impede and filter percolating ground surface polluting liquid into the aquiferous unit. This concept was derived from Henriet’s 1976 relationship that “the protective capacity of the overburden (vadose zone) is proportional to its longitudinal conductance \( S \) which in terms of aquifer protection gets a dimension of time (infiltration time)”. The second order geo-electric parameter (Dar Zarrouk parameter) was evaluated from the primary/first order parameters (using equation 1) (thickness and resistivity) of the geo-electric subsurface layers which were used in the classification of the protective capacity of the vadose zone over the aquifer systems of the area. According to Oladapo [20] the protective capacity of the vadose zone over an aquifer can be classified based on total unit conductance \( (\sum S) \): Excellent \((S > 5)\), very good \((5 \leq S < 10)\), good \((0.7 \leq S < 5)\), moderate \((0.2 \leq S < 0.7)\), weak \((0.1 \leq S < 0.2)\) and poor \((S < 0.1)\).

As the hydraulic conductivity is directly proportional to the resistivity [13] and the product of the resistivity for its thickness, it is defined as being the transverse resistance \( (T) \), on a purely empirical basis and it can be admitted that the transmissivity of an aquifer is directly proportional to its transverse resistance [12]. Clay layer corresponds to low resistivities and low hydraulic conductivities, and vice versa, hence, the protective capacity of the overburden could be considered as being proportional to the ratio of thickness to resistivity - longitudinal conductance \( (S) \). In the present study, layers found above the potential aquifers have generally been considered as the vadose zone and as such their transmissivities \( (T) \) have been computed using equation 2 above. Adopting Culled 1982 classification the \( T \) values were categorized as follows: Very high transmissivity magnitude \((T \geq 1000)\), High transmissivity magnitude \((100 \leq T < 1000)\), intermediate transmissivity magnitude \((10 \leq T < 100)\), Low transmissivity magnitude \((1 \leq T < 10)\), very low transmissivity magnitude \((0.1 \leq T < 1)\) and imperceptible transmissivity magnitude \( (T < 0.1) \).

### 3. Result and Discussion

#### Table 1. Result of Interpretation of VES Curves from the Study area

<table>
<thead>
<tr>
<th>VES No.</th>
<th>Layers No.</th>
<th>R(Ω)</th>
<th>Layer Thickness (m)</th>
<th>Inferred Lithology</th>
<th>Curves Types and % error</th>
<th>Inferred Aquifer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.</td>
<td>150</td>
<td>2.92</td>
<td>- Top soil</td>
<td>HK</td>
<td>Aquifer</td>
</tr>
<tr>
<td></td>
<td>2.</td>
<td>17.4</td>
<td>3.25</td>
<td>- Weathered basement</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.</td>
<td>7188</td>
<td>8</td>
<td>- Fractured basement</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.</td>
<td>31.3</td>
<td>-</td>
<td>Fresh basement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1.</td>
<td>149</td>
<td>1.55</td>
<td>- Top soil</td>
<td>QH</td>
<td>Aquifer</td>
</tr>
<tr>
<td></td>
<td>2.</td>
<td>110</td>
<td>10</td>
<td>- Weathered basement</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.</td>
<td>31.6</td>
<td>15.6</td>
<td>- Fractured basement</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.</td>
<td>21097</td>
<td>-</td>
<td>Fresh basement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1.</td>
<td>49.2</td>
<td>5.25</td>
<td>- Top soil</td>
<td>H</td>
<td>Aquifer</td>
</tr>
<tr>
<td></td>
<td>2.</td>
<td>376</td>
<td>13</td>
<td>- Weathered basement</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.</td>
<td>27.7</td>
<td>-</td>
<td>Fresh basement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1.</td>
<td>86.1</td>
<td>1.48</td>
<td>- Top soil</td>
<td>HA</td>
<td>Aquifer</td>
</tr>
<tr>
<td></td>
<td>2.</td>
<td>26.1</td>
<td>1.23</td>
<td>- Weathered basement</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.</td>
<td>104</td>
<td>8.29</td>
<td>- Fractured basement</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.</td>
<td>425</td>
<td>-</td>
<td>Fresh basement</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.</td>
<td>2.</td>
<td>3.</td>
<td>4.</td>
<td>5.</td>
<td>Aquifer Type</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>5</td>
<td>163</td>
<td>3.84</td>
<td>Top soil</td>
<td>K</td>
<td>Aquifer</td>
<td></td>
</tr>
<tr>
<td></td>
<td>388</td>
<td>18</td>
<td>-Weathered basement</td>
<td>- Fresh basement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>37.3</td>
<td>6.93</td>
<td>Top soil</td>
<td>AH</td>
<td>Aquifer</td>
<td></td>
</tr>
<tr>
<td></td>
<td>55.6</td>
<td>5.39</td>
<td>-Weathered basement</td>
<td>- Fractured basement</td>
<td>- Fresh basement</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>99.1</td>
<td>5</td>
<td>Top soil</td>
<td>QH</td>
<td>Aquifer</td>
<td></td>
</tr>
<tr>
<td></td>
<td>55.4</td>
<td>13</td>
<td>-Weathered Basement</td>
<td>- Fractured Basement</td>
<td>- Fresh Basement</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>24.8</td>
<td>2.06</td>
<td>Top soil</td>
<td>HA</td>
<td>Aquifer</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.26</td>
<td>2.96</td>
<td>-Weathered basement</td>
<td>- Fractured basement</td>
<td>- Fresh basement</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>171</td>
<td>1.57</td>
<td>Top soil</td>
<td>KH</td>
<td>Aquifer</td>
<td></td>
</tr>
<tr>
<td></td>
<td>399</td>
<td>0.66</td>
<td>-Weathered basement</td>
<td>- Fractured basement</td>
<td>- Fresh basement</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>3.9</td>
<td>0.142</td>
<td>Top soil</td>
<td>HK</td>
<td>Aquifer</td>
<td></td>
</tr>
<tr>
<td></td>
<td>54.3</td>
<td>3.46</td>
<td>-Weathered basement</td>
<td>- Fractured basement</td>
<td>- Fresh basement</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>80.7</td>
<td>5.43</td>
<td>Top soil</td>
<td>H</td>
<td>Aquifer</td>
<td></td>
</tr>
<tr>
<td></td>
<td>26.1</td>
<td>3.58</td>
<td>-Weathered basement</td>
<td>- Fresh basement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>251</td>
<td>2.46</td>
<td>Top soil</td>
<td>HKH</td>
<td>Aquifer</td>
<td></td>
</tr>
<tr>
<td></td>
<td>116</td>
<td>1.93</td>
<td>-Slightly Weathered basement</td>
<td>-Fractured basement</td>
<td>- Fresh basement</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>89.8</td>
<td>2.81</td>
<td>Top soil</td>
<td>KH</td>
<td>Aquifer</td>
<td></td>
</tr>
<tr>
<td></td>
<td>220</td>
<td>5.63</td>
<td>-Weathered basement</td>
<td>-Fractured basement</td>
<td>- Fresh basement</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>53.8</td>
<td>0.323</td>
<td>Top soil</td>
<td>HK</td>
<td>Aquifer</td>
<td></td>
</tr>
<tr>
<td></td>
<td>147</td>
<td>9.99</td>
<td>-Weathered basement</td>
<td>-Fractured basement</td>
<td>- Fresh basement</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>39.3</td>
<td>0.9</td>
<td>Top soil</td>
<td>KHK</td>
<td>Aquifer</td>
<td></td>
</tr>
<tr>
<td></td>
<td>62.3</td>
<td>1.02</td>
<td>-Slightly Weathered basement</td>
<td>-Fractured basement</td>
<td>- Fresh basement</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>28.1</td>
<td>1.64</td>
<td>Top soil</td>
<td>HKH</td>
<td>Aquifer</td>
<td></td>
</tr>
<tr>
<td></td>
<td>362</td>
<td>1.67</td>
<td>-Slightly Weathered basement</td>
<td>-Fractured basement</td>
<td>- Fresh basement</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>62.7</td>
<td>9.78</td>
<td>Top soil</td>
<td>H</td>
<td>Aquifer</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10.3</td>
<td>13.4</td>
<td>-Weathered basement</td>
<td>- Fresh basement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>236</td>
<td>0.783</td>
<td>Top soil</td>
<td>HK</td>
<td>Aquifer</td>
<td></td>
</tr>
<tr>
<td></td>
<td>113</td>
<td>3.38</td>
<td>-Weathered basement</td>
<td>-Fractured basement</td>
<td>- Fresh basement</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>114</td>
<td>0.941</td>
<td>Top soil</td>
<td>QH</td>
<td>Aquifer</td>
<td></td>
</tr>
<tr>
<td></td>
<td>29.2</td>
<td>11.6</td>
<td>-Weathered basement</td>
<td>-Fractured basement</td>
<td>- Fresh basement</td>
<td></td>
</tr>
</tbody>
</table>
### 3.1 Geo-Electric Section

The data analysis from the study area shows a three to five layers geo-electric succession (Figure 3 and 4). This succession comprises of the dry topsoil, slightly weathered, weathered basement, fractured basement and Fresh basement. Weathered and fractured zones represented by low and fairly high resistivity units, respectively, are considered to be the potential groundwater bearing zones. Dike el al. [8]

![Geo Electric Section](image)

**Figure 3.** Geo electric Section of Ves 03, 05, 11 and 17 (3 layers)
Figure 4. Geo electric Section of Ves 22, 23 25 and 26 (3 layers)

Figure 5. A three layer type curve

Figure 6. Geo electric Section of Ves 1, 2, 4, 6, 7 and 8 (4 layers)

Figure 7. Geo electric Section of Ves 9, 10, 13, 14, 18 and 19 (4 layers)

Figure 8. A four layer type curve

Figure 9. Geo electric Section of Ves 12, 15, 16, 20 and 28 (5 layers)

Figure 10. A five layer Type Curve

Table 2. Evaluation of the Longitudinal Conductance and Transverse Resistance of the Layers Obtained from each VES Location

<table>
<thead>
<tr>
<th>VES NO</th>
<th>S1Ω</th>
<th>S2Ω</th>
<th>S3Ω</th>
<th>S4Ω</th>
<th>T1Ω</th>
<th>T2Ω</th>
<th>T3Ω</th>
<th>T4Ω</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0197</td>
<td>0.2443</td>
<td>0.0011</td>
<td>444.00</td>
<td>73.95</td>
<td>57504.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.0104</td>
<td>0.0909</td>
<td>0.4937</td>
<td>230.95</td>
<td>1100.00</td>
<td>492.96</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.1067</td>
<td>0.0346</td>
<td>258.30</td>
<td>4888.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.0172</td>
<td>0.0457</td>
<td>0.0797</td>
<td>127.43</td>
<td>33.09</td>
<td>862.16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.0236</td>
<td>0.0464</td>
<td>625.92</td>
<td>6984.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.1859</td>
<td>0.0969</td>
<td>0.0282</td>
<td>258.64</td>
<td>299.68</td>
<td>1583.16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>0.0505</td>
<td>0.2347</td>
<td>1.0482</td>
<td>495.50</td>
<td>720.20</td>
<td>288.84</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>0.0831</td>
<td>0.6854</td>
<td>0.0017</td>
<td>51.09</td>
<td>12.44</td>
<td>188348.48</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>0.0002</td>
<td>0.0017</td>
<td>0.2660</td>
<td>268.47</td>
<td>263.34</td>
<td>6227.10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>0.0364</td>
<td>0.0637</td>
<td>0.2786</td>
<td>0.55</td>
<td>187.88</td>
<td>24.83</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

DOI: https://doi.org/10.30564/jees.v2i2.1633
### Table 3. Evaluation of the Total Longitudinal Conductance, Total Transverse Resistance and Average Longitudinal Conductance and Average Transverse Resistance each VES Location

<table>
<thead>
<tr>
<th>VES NO</th>
<th>S</th>
<th>PL</th>
<th>T</th>
<th>Pt</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.2651</td>
<td>57.37</td>
<td>58021.95</td>
<td>3814.72</td>
</tr>
<tr>
<td>2</td>
<td>0.5950</td>
<td>45.78</td>
<td>1823.91</td>
<td>67.18</td>
</tr>
<tr>
<td>3</td>
<td>0.1413</td>
<td>129.16</td>
<td>5146.30</td>
<td>281.99</td>
</tr>
<tr>
<td>4</td>
<td>0.1426</td>
<td>77.14</td>
<td>1022.68</td>
<td>92.97</td>
</tr>
<tr>
<td>5</td>
<td>0.07</td>
<td>312</td>
<td>7609.91</td>
<td>348.44</td>
</tr>
<tr>
<td>6</td>
<td>0.1501</td>
<td>0.06</td>
<td>2141.48</td>
<td>112.71</td>
</tr>
<tr>
<td>7</td>
<td>1.3334</td>
<td>26.55</td>
<td>1504.54</td>
<td>42.50</td>
</tr>
<tr>
<td>8</td>
<td>0.7702</td>
<td>0.0031</td>
<td>18412.01</td>
<td>1753.52</td>
</tr>
<tr>
<td>9</td>
<td>0.2769</td>
<td>155.04</td>
<td>6758.91</td>
<td>157.44</td>
</tr>
<tr>
<td>10</td>
<td>0.3787</td>
<td>16.46</td>
<td>213.26</td>
<td>34.21</td>
</tr>
<tr>
<td>11</td>
<td>0.2045</td>
<td>44.06</td>
<td>531.64</td>
<td>59.01</td>
</tr>
<tr>
<td>12</td>
<td>0.5494</td>
<td>33.02</td>
<td>2599.36</td>
<td>143.29</td>
</tr>
<tr>
<td>13</td>
<td>0.6407</td>
<td>26.66</td>
<td>1618.81</td>
<td>94.78</td>
</tr>
<tr>
<td>14</td>
<td>0.0901</td>
<td>95.95</td>
<td>6551.74</td>
<td>355.40</td>
</tr>
<tr>
<td>15</td>
<td>0.1412</td>
<td>62.04</td>
<td>2536.07</td>
<td>289.51</td>
</tr>
<tr>
<td>16</td>
<td>0.4004</td>
<td>61.61</td>
<td>2659.96</td>
<td>107.82</td>
</tr>
<tr>
<td>17</td>
<td>1.4568</td>
<td>15.91</td>
<td>752.57</td>
<td>32.47</td>
</tr>
<tr>
<td>18</td>
<td>0.1961</td>
<td>28.98</td>
<td>544.91</td>
<td>95.88</td>
</tr>
<tr>
<td>19</td>
<td>1.7621</td>
<td>15.97</td>
<td>625.39</td>
<td>22.22</td>
</tr>
<tr>
<td>20</td>
<td>0.5163</td>
<td>89.23</td>
<td>5075.03</td>
<td>110.16</td>
</tr>
<tr>
<td>21</td>
<td>0.6040</td>
<td>13609.6</td>
<td>142.69</td>
<td>157.88</td>
</tr>
<tr>
<td>22</td>
<td>0.2388</td>
<td>2723.46</td>
<td>15.11</td>
<td>108.50</td>
</tr>
<tr>
<td>23</td>
<td>0.2247</td>
<td>1694.28</td>
<td>72.99</td>
<td>103.31</td>
</tr>
<tr>
<td>24</td>
<td>0.1079</td>
<td>60839.72</td>
<td>559.78</td>
<td>1007.28</td>
</tr>
<tr>
<td>25</td>
<td>0.1515</td>
<td>39141.92</td>
<td>436.96</td>
<td>519.27</td>
</tr>
<tr>
<td>26</td>
<td>0.2203</td>
<td>429.44</td>
<td>29.05</td>
<td>67.10</td>
</tr>
<tr>
<td>27</td>
<td>299.7648</td>
<td>13432.92</td>
<td>0.21</td>
<td>216.31</td>
</tr>
<tr>
<td>28</td>
<td>1.8779</td>
<td>5681.01</td>
<td>29.45</td>
<td>102.73</td>
</tr>
<tr>
<td>29</td>
<td>0.199</td>
<td>7076.62</td>
<td>177.89</td>
<td>0.01</td>
</tr>
<tr>
<td>30</td>
<td>0.1606</td>
<td>1618.04</td>
<td>93.40</td>
<td>107.87</td>
</tr>
</tbody>
</table>
3.2 Protective Capacity Evaluation of the Vadoze Zone

The nature of the materials that overlie the mapped aquifers were evaluated using the layer parameters (i.e. resistivity and thickness), to determine its capacity to prevent infiltration of unwanted fluids into the aquifer. It should be noted that the earth materials act as natural filter to percolating fluids; therefore its ability to retard and filter percolating ground surface polluting fluids is a measure of its protective capacity. That is to say that the geologic materials overlying an aquifer could act as seal in preventing the fluid from percolating into it.

The longitudinal unit conductance (S) values of the overburden materials obtained from the study area, ranges from 0.0018 to 0.4056 ohms (Table 4) with a mean value of 0.0135 ohms. Clayey overburden, which is characterized by relatively high longitudinal conductance, offers protection to the underlying aquifer. According to the classification of Oladapo and Akintorinwa, the longitudinal unit conductance (S) values from the study area enabled us to classify the area into poor, (S<0.1), weak, (0.1≤S<0.2), moderate (0.2≤S<0.7) and good, (0.7≤S<5), very good (5≤ S<10) and excellent (S>10) protective capacity zones. Where the conductance is greater than 10 mhos are considered zones of excellent protective capacity. This study has revealed that the overburden materials (vadoze zone) in the VES 01, 04, 05, 08, 09, 11, 12, 13, 14, 15, 16, 18, 20, 22, 23, 24, 25, 26, 27, 29 and 30 have poor protective capacity while VES 02, 03, 06, 10, 17, 21 and 28 are characterized by weak protective capacity. Furthermore, the VES 07, 19 and 27 are found to have a moderate protective capacity. The result revealed that 90% of VES within the study area have poor protective capacity, while 10% have weak to moderate protective capacity.

Table 4. Summary of the vadoze zone protective capacity over the aquifer systems of the study area

<table>
<thead>
<tr>
<th>VES No</th>
<th>No. of Overburden layers</th>
<th>Lithology</th>
<th>Longitudinal Conductance (S)</th>
<th>Protective Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.</td>
<td>- Top soil</td>
<td>0.02</td>
<td>(S&lt;0.1), (Poor)</td>
</tr>
<tr>
<td>2</td>
<td>1. 2.</td>
<td>- Top soil - Weathered basement</td>
<td>0.10</td>
<td>(0.1≤S&lt;0.2) (Weak)</td>
</tr>
<tr>
<td>3</td>
<td>1.</td>
<td>- Top soil</td>
<td>0.11</td>
<td>(0.1≤S&lt;0.2) (Weak)</td>
</tr>
<tr>
<td>4</td>
<td>1. 2.</td>
<td>- Top soil - Weathered basement</td>
<td>0.06</td>
<td>(S&lt;0.1), (Poor)</td>
</tr>
<tr>
<td>5</td>
<td>1.</td>
<td>- Top soil</td>
<td>0.02</td>
<td>(S&lt;0.1), (Poor)</td>
</tr>
<tr>
<td>6</td>
<td>1.</td>
<td>- Top soil</td>
<td>0.19</td>
<td>(0.1≤S&lt;0.2) (Weak)</td>
</tr>
<tr>
<td>7</td>
<td>1. 2.</td>
<td>- Top soil - Weathered basement</td>
<td>0.03</td>
<td>(S&lt;0.1), (Poor)</td>
</tr>
<tr>
<td>8</td>
<td>1.</td>
<td>- Top soil</td>
<td>0.08</td>
<td>(S&lt;0.1), (Poor)</td>
</tr>
<tr>
<td>9</td>
<td>1. 2.</td>
<td>- Top soil - Weathered basement</td>
<td>0.01</td>
<td>(S&lt;0.1), (Poor)</td>
</tr>
<tr>
<td>10</td>
<td>1. 2.</td>
<td>- Top soil - Weathered basement</td>
<td>0.1</td>
<td>(0.1≤S&lt;0.2) (Weak)</td>
</tr>
<tr>
<td>11</td>
<td>1.</td>
<td>- Top soil</td>
<td>0.07</td>
<td>(S&lt;0.1), (Poor)</td>
</tr>
<tr>
<td>12</td>
<td>1. 2. 3.</td>
<td>- Top soil - Slightly weathered - Weathered basement</td>
<td>0.04</td>
<td>(S&lt;0.1), (Poor)</td>
</tr>
<tr>
<td>13</td>
<td>1. 2.</td>
<td>- Top soil - Weathered basement</td>
<td>0.06</td>
<td>(S&lt;0.1), (Poor)</td>
</tr>
<tr>
<td>14</td>
<td>1.</td>
<td>- Top soil</td>
<td>0.006</td>
<td>(S&lt;0.1), (Poor)</td>
</tr>
<tr>
<td>15</td>
<td>1. 2.</td>
<td>- Top soil - Weathered basement</td>
<td>0.04</td>
<td>(S&lt;0.1), (Poor)</td>
</tr>
<tr>
<td>16</td>
<td>1. 2.</td>
<td>- Top soil - Weathered basement</td>
<td>0.06</td>
<td>(S&lt;0.1), (Poor)</td>
</tr>
<tr>
<td>17</td>
<td>1.</td>
<td>- Top soil</td>
<td>0.16</td>
<td>(0.1≤S&lt;0.2) (Weak)</td>
</tr>
<tr>
<td>18</td>
<td>1. 2.</td>
<td>- Top soil - Weathered basement</td>
<td>0.03</td>
<td>(S&lt;0.1), (Poor)</td>
</tr>
</tbody>
</table>
and aquifer transmissivity. The transmissivity values obtained within the area of study range from 0.55 to 1195.68 \( \Omega^2 \) with a mean value of 72.47. The results as presented in (Table 5) and figure 11 show that the vadose zone in the study area majorly offers less protection to the underlying aquifer systems. Generally from the analysis it shows that 80% of the points investigated have High, 3.3% Very High, 13.3% intermediate and 3.3% very low Transmissivity magnitude. The points with high to very high values of T also corresponded with those with poor to weak protective capacity as represented by table 4 and figure 9. These two parameters have thus revealed that the underlying aquifer systems are highly vulnerable to any contaminants emanating from surface activities.

**Table 5.** Vadose zone Transmissivity in relation to Transverse Resistance within the VES locations

<table>
<thead>
<tr>
<th>VES NO</th>
<th>Pa of the vadose zone</th>
<th>Thickness</th>
<th>Transmissivity</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>150</td>
<td>2.96</td>
<td>444.00</td>
<td>High</td>
</tr>
<tr>
<td>2</td>
<td>149</td>
<td>1.55</td>
<td>230.95</td>
<td>High</td>
</tr>
<tr>
<td>3</td>
<td>49.2</td>
<td>5.25</td>
<td>258.30</td>
<td>High</td>
</tr>
<tr>
<td>4</td>
<td>86.1</td>
<td>1.48</td>
<td>127.43</td>
<td>High</td>
</tr>
<tr>
<td>5</td>
<td>163</td>
<td>3.84</td>
<td>625.92</td>
<td>High</td>
</tr>
<tr>
<td>6</td>
<td>37.3</td>
<td>6.93</td>
<td>258.64</td>
<td>High</td>
</tr>
<tr>
<td>7</td>
<td>99.1</td>
<td>5</td>
<td>495.50</td>
<td>High</td>
</tr>
<tr>
<td>8</td>
<td>24.8</td>
<td>2.06</td>
<td>51.09</td>
<td>Intermediate</td>
</tr>
</tbody>
</table>

**Figure 11.** Vadose zone protective capacity Map

**3.3 Vadose Zone Transmissivity**

The transmissivity values of the Vadose zone were evaluated using a relationship between transverse resistance
### 4. Conclusion

An assessment of the protective capacity of the vadose zone overlying aquifer systems in Kaltungo area was carried out using secondary geo-electric parameters computed from VES data generated from 30 points in the field. The parameters considered here are longitudinal conductance (S) and Transverse Resistance here synonymous with Transmissivity (T) computed based on established relation between geo-electric resistivity and aquifer parameters (Dar Zarouk Parameters) thus;

\[ S = \frac{h}{\rho_a} \]  
(1)  
\[ T = \frac{h}{\rho_a} \]  
(2)

The results from the two parameters as presented in tables 4 and 5 revealed that the vadose zone (overburden materials) in the study area offer poor protection to the underlying aquifer systems. The study has confirmed that using geo-electric parameters can be useful in groundwater quality studies. The relation between electrical resistivity, layer thickness and aquifer properties has also been confirmed by this study hence combining geophysical resistivity methods and other groundwater quality vulnerability mapping can form a good basis for groundwater sustainability studies.

### Acknowledgement

The Authors are grateful to the staff of Holocene Engineering Nigerian limited for providing equipment and man power for field work and the management of Gombe State University for sponsoring part of the data collection.

### Reference


ARTICLE

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

Philip Gathogo Muiruri* Joy A. Obando Ishmail O. Mahiri
Department of Geography, Kenyatta University, Kenya, 43844, Nairobi

ARTICLE INFO

Article history
Received: 29 May 2020
Accepted: 22 June 2020
Published Online: 31 October 2020

Keywords:
Channel incision
Ephemeral stream
Morphologic response
Sand mining
Sustainable development

ABSTRACT

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

1. Introduction

River sand mining is an activity that have been ongoing over centuries, with increasing frequency and intensity rising over time [1]. The activity has been exacerbated by the rising need for grade sand in the rapidly growing construction industry across the world. According to [2], sand mining from river channels in the world at the moment is unsustainable as it is estimated to exceed the natural replacement rates. The current annual global sand consumption rate slightly exceed 40 billion tonnes [2], which is estimated to be twice as much as the annual total amount of sand transported by rivers of the world as calculated by [3]. In line with that, [4] posits that
sand extraction rates from river channels exceeding the natural replenishment lead to adverse environmental effects. Sand mining, just like bank protection and damming of the river intercepts sediments flow in a river channel which creates a sediment deficit downstream \[5\].

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

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

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

As \[14\] points out, sand mining results obtained in one site lack application in another due to variation in many local and regional factors, and this necessitated a local study in River Tyaa. Additionally, need to achieve sustainable development dictates environmental friendly exploitation of natural resources at our disposal to ensure constant supply both for current and posterity needs as well as minimal disruption of the ecosystem. In line with that and in light of the rampant nature in which sand mining is taking place in Kenyan rivers, this study set out to establish the geomorphic effects of sand mining in River Tyaa in Kitui County. This was significant because it informed development of sound site-specific proactive rather than reactive sand mining strategies which captures the spirit of the Sustainable Development Goals (SDGs), particularly the one emphasizing need for sustainable production and consumption, hence prioritization of ecological conservation while exploiting natural resources \[20\].

**Conceptual Model of the Study**

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

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

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

![Figure 1. A Conceptual Model of River Channel’s Response to Sand Mining](source)

**Source:** Modified from Huggett (2007)

### 2. Methodology

#### 2.1 Study Area

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

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

![Figure 2. Study Area Showing River Tyaa in Kitui County, Kenya](source)

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

#### 2.2 Sampling Design

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

![Figure 3. Active Sand Mining Sites along River Tyaa](source)

**Source:** Author, (2019)

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

![Figure 4. Active Sand Mining Site and the Control Sites](image)

Source: Author, (2019)

### 2.3 Data Collection

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

### 2.4 Data Analysis

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

\[
Y = \frac{e^{\left(\alpha + \sum_{i=1}^{n} \beta_i x_i \right)}}{1 + e^{\left(\alpha + \sum_{i=1}^{n} \beta_i x_i \right)}}
\]

In the equation, \( Y \) is the river morphology, \( e \) is the exponential value, \( \alpha \) is the intercept value in the normal linear regression model, \( \beta_i \) is the gradient for an independent variable \( X_i \) while \( \beta_{nxn} \) represents the gradient values multiplied by the respective independent variables considered in this case, up to the last variable.

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

### 3. Results and Discussions

The model compared data from the active sand mining site with that of the control sites. It gave out odds ratios which indicated the level of significance of each variable in influencing morphology of the River Tyaa channel. The results pointed out that sand mining had significantly affected the river channel’s width, depth and slope angles.

#### Table 1. The Multiple Logistic Regression Model Output

<table>
<thead>
<tr>
<th>Variables</th>
<th>Model Coefficients</th>
<th>Odds Ratio</th>
<th>Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel Width</td>
<td>0.2078</td>
<td>1.531</td>
<td>0.012457e-05 to 1.235645e-02</td>
</tr>
<tr>
<td>Channel Depth</td>
<td>0.3556</td>
<td>1.527</td>
<td>0.0025456e-03 to 0.1255678e-02</td>
</tr>
<tr>
<td>Channel Slope Angles</td>
<td>0.4910</td>
<td>1.634</td>
<td>0.2651254e-06 to 0.2154579e-03</td>
</tr>
</tbody>
</table>

#### 3.1 The Effect of Sand Mining on the Channel Width

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

Plate 1. Effects of Sand Mining on Channel Width
Source: Author, February (2019)

3.2 The Contribution of Sand Mining to the Channels Depth

The results indicate that sand mining had caused a statistically significant increase in channels depth as shown by the odds ratio in Table 1. Compared to the control sites, it is clear that a unit increase in sand mined at the active site led to 52.7% increase in odds ratio for increased depth of the channel compared to the control sites. Similar findings were arrived at by \textsuperscript{[28]} who established that uncontrolled sand mining led to depletion of sand deposits on the river bed hence increased depth. Further,\textsuperscript{[14]} remarked that alteration of river channels depth comes about where the sand mining rates exceed the natural replacement rates. As depicted in Plate 2, sand mining in River Tyaa has caused increase in depth of the channel, a factor that indicates that sand mining is taking place at a higher rate compared to the natural replacement. As explained by\textsuperscript{[29,9]}, high rates of sand mining distorts the alluvial aquifer on the river beds and flood plains thus causing a downshift of the water table hydrologically connected to the river. The implication of this is drying up of the riparian vegetation which may no longer access underground water which in turn exposes the river banks to more erosion and instability leading to further distortion of the channel geometry.

Plate 2. Influence of Sand Mining on River Channel’s Depth and Slope Angles
Source: Author, February (2019)

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

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

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

4. Conclusions and Recommendations

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

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

References


Influence of Temperature and Relative Humidity on Air Pollution in Addis Ababa, Ethiopia

Mulu Fikeraddis   Lake Endeshaw*
Department of Physics, Worabe University, Worabe, Ethiopia

ARTICLE INFO
Article history
Received: 19 August 2020
Accepted: 3 September 2020
Published Online: 30 October 2020

Keywords:
Atmospheric pollutants
Carbon monoxide
Nitrogen oxides
Relative humidity
Temperature

ABSTRACT
In this paper we access the effects of two atmospheric variables (temperature and relative humidity) on two important pollutants in the atmosphere (Nitrogen oxides (NOx) and carbon monoxide (CO)) by using one year (2016) data of Addis Ababa. Temperature has impact on atmospheric mixing and cause for the reduction of NOx as temperature increases. There are positive correlation between temperature and CO concentration from January to April with \( R^2 = 0.69 \), negative correlation from May to August with \( R^2 = 0.92 \) and no correlation for the remaining months. NOx and CO have moderate positive and negative correlation with relative humidity during the months January-April \( (R^2 = 0.294 \text{ for NOx and } R^2 = 0.291 \text{ for CO}) \) and in the months May-August \( (R^2 = 0.97 \text{ and } R^2 = 0.15 \) for NOx and CO respectively. But there are no clear correlation between the NOx and CO with relative humidity from September-December. NOx concentrations during wet season was almost about twice that of the dry season, but no such difference was observed in the case of CO. The seasonal average air temperature in wet season is relatively lower than dry season. NOx exhibited positive and CO negative seasonal correlations with relative humidity.

1. Introduction

Meteorological parameters such as temperature and relative humidity play a significant role in affecting air pollutants in urban environment [1]. Air pollution occurs within the atmospheric planetary boundary layer under the combined effects of meteorological factors, earth surface topographic features and the release of air pollutants from various sources [2,3]. Meteorological parameters are having great importance in transportation, dispersion and natural cleaning of the air pollutants in the atmosphere [4,5,6,7]. The most important role of meteorological parameters are in the dispersion, transformation and removal of air pollutants from atmosphere [8,9,10]. High pollution levels can be expected during fair weather conditions resulting from local wind system and strong temperature inversions [11,12].

In developing countries like Ethiopia, the transport sector accounts for 49% of NOx emissions and the power sector 25%, the industrial sector 11%, the residential com-
Commercial sectors 10% and other sources 5% \cite{13,14,15,16}. Nitrogen oxides (NOx) are mixes of gases that are composed of nitrogen and oxygen. Two of the most toxicologically significant nitrogen oxides are nitric (NO) and nitrogen dioxide (NO2) and collectively represented as NOx, which are emitted by vehicles. The reaction of nitrogen dioxide with chemicals produced by sunlight leads to the formation of nitric acid which is a major constituent of acid rain. Nitrogen dioxide also reacts with sunlight which leads to the formation of ozone and smog conditions in the air we breathe. Carbon monoxide (CO) is a colorless and odorless gas that can be harmful when inhaled in large amounts and its greatest sources are cars, trucks and other vehicles or machinery that burn fossil fuels (petrol), wood and coal (from home heating and industry) \cite{17,18,19,20,21}. Carbon monoxide is the primarily pollutant which is emitted from its sources directly to the atmosphere \cite{22,23,24,25,26}.

Nowadays, vehicles and factories are increasing in Addis Ababa and many of vehicles are second-hand (old) with out emission controls and they are considered as major air polluters of the city. According to National Meteorological Agency (NMA) of Ethiopia most vehicles have no emission controls and about 53% of the total vehicles in Addis Ababa are more than 20 years old. Old vehicles emit hydrocarbons and smoke to the atmosphere up to five times the rate of emissions from new vehicles \cite{27,28,29,30}. Such interventions require appropriate policy framework and institutional capacity for implementation. In this regard, the Roads Transport Authority (RTA) has power to prepare standards relating to smoke gas and vapor emitted from the exhaust pipes of vehicles, as per the requirements of Environmental Policy of Ethiopia (EPA). EPA on the other hand is expected to formulate Air Quality Standards (AQS) in consultation with the RTA.

Thus, this study focuses on the influence of temperature and relative humidity on concentrations of NOx and CO in one year data (2016) of Addis Ababa. Air pollutants such as nitrogen dioxide has been linked to increases in asthma symptoms and reduced lung development and function in children \cite{31}. Nitrogen dioxide can decrease the lungs’ defenses against bacteria, making them more susceptible to infections. Carbon monoxide is readily absorbed by the lungs and interferes with the blood’s ability to carry oxygen. Therefore knowing concentrations of these two gases are a paramount importance \cite{29,32}. Besides, finding meteorological parameters that have influences on their concentrations is also necessary to control their concentrations. Hence, this study has a wide range of significant for the researcher, city administer, Addis Ababa Environmental Protection Authority (AAEPA), Federal Transport Authority (FTA), National Meteorological Service agency (NMSA) and for the society.

2. Data and Methods

Addis Ababa is a capital city of Ethiopia and the city has a complex mix of highland climate zones with temperature differences of up to 10°C (18°F), depending on elevation and prevailing wind patterns \cite{40}. Addis Ababa is located at geographic location in 9.00° N and 38.80° E and it is one of the most traffic-related pollutant cities in Ethiopia. The main contributors to air pollution in the city are domestic heating, private cars and public vehicles. In this study, the data of NOx and CO concentrations was collected from Ethiopian Meteorological Agency at Addis Ababa station as secondary data. Meteorological parameters (temperature and relative humidity) were also obtained from the National Meteorological Services Agency (NMSA) of Ethiopia. The data was recorded during the year 2016 from Ethiopian Meteorological Agency at Addis Ababa station.

The data of meteorological parameters (temperature and relative humidity) and concentrations of NOx and CO were organized using Microsoft Excel and the averaged value of pollutant concentrations and meteorological parameters were averaged to obtain seasonal values over the entire year. Time series of monthly and seasonal variability of the concentrations of NOx and CO were plotted using Matlab software. Regression analyses between concentrations of NOx and CO and air temperature and relative humidity were also determined by using Matlab software.

3. Results and Discussions

3.1 Influence of Temperature and Relative Humidity on Monthly-averaged Concentration of NOx and CO

The influence of temperature on monthly-averaged NOx and CO concentrations are shown on Figure 1. The plots show weak negative correlation ($R^2 = 0.30$) and no collection ($R^2 = 0.01$) for NOx and CO respectively. Similarly, Hosseinibalam and Hejazi \cite{33} have found that weak negative collection ($R^2 = 0.18$) in Isfahan at Azadi station. The relative humidity shows weak negative correlation ($R^2 = 0.14$) and ($R^2 = 0.07$) for NOx and CO respectively as shown in Figure 1.
Despite the weak correlation the negative slope manifests inverse linear relationship as shown in Figure 2, which is less concentration (more dispersion) as temperature increases. Similar weak correlation was also obtained by Bathmanaban [4] in between the NOx and temperature. Ocak and Demircioglu [37] have obtained a more satisfactory correlation with $R^2 = 0.73$ between the NOx and temperature. It is obvious that NOx concentrations decrease with increasing temperature but what Akkaya and Pazarlhoglu [38] have observed for pre and post monsoon seasons is contrary to this result. However, their result for the rainy seasons agree with this finding.

**Figure 1.** Influences of temperature and relative humidity on monthly-averaged NOx and CO concentrations in the year 2016

**Figure 2.** Linear regression between temperature and monthly-averaged NOx concentration using averaged data of months

### 3.2 Influence of Temperature on NOx and CO Concentrations

As shown in Figure 3 the daily-averaged data of CO over the entire year shows no correlation between CO concentration and temperature. But other studies such as Witz and Moore [34] showed the relationships between the temperature and CO and found regression coefficients that varied between 0.68 and 0.73. Observation of Figure 3 reveals positive correlation between temperature and CO concentration from January to April with ($R^2 = 0.69$), negative correlation from May to August with ($R^2 = 0.92$) and no correlation for the remaining months.
3.3. Correlation between Concentrations of NO\textsubscript{x} and CO with Relative Humidity (RH)

Correlation between NO\textsubscript{x} concentrations and relative humidity is very weak correlation ($R^2 = 0.15$). This is in agreement with Jayamurugan et al. \cite{35} have no significant correlation was found between humidity and NO\textsubscript{x} in all seasons. The correlation $R^2 = 0.15$ shows that the independent variable of relative humidity included in the model are able to explain 15% of the variation in the dependent variable of NO\textsubscript{x}. The NO\textsubscript{x} concentration has a very weak dependence and this means that 15% of NO\textsubscript{x} depends on relative humidity and 85% is indeterminate. The correlation between CO and relative humidity over days of the year 2016 was investigated by linear regression analysis and the scatter plots are shown in Figure 1. There is no correlation between CO concentration and relative humidity. However, monthly bar plots show some sort of pattern between both gases and RH as shown in Figure 4. But according to Ocak \cite{39} relative humidity is a moderately linked parameter to concentrations of NO\textsubscript{x} and CO pollutants.

The results of the regression analysis revealed that NO\textsubscript{x} and CO have moderate positive and negative correlation with relative humidity during the months January-April ($R^2 = 0.294$ for NO\textsubscript{x} and $R^2 = 0.291$ for CO) respectively. As shown in Figure 4, the relative humidity is a moderately linked parameter to concentrations of NO\textsubscript{x} and CO pollutants. The correlations in the months May-August are $R^2 = 0.97$ and $R^2 = 0.15$ for NO\textsubscript{x} and CO respectively. But from September-December there are no clear correlation between the NO\textsubscript{x} and CO with relative humidity. The concentration of CO decreases with increasing relative humidity and the concentration of NO\textsubscript{x} increases with increasing relative humidity as observed by \cite{37}.

![Figure 3](image1.png)

**Figure 3.** Correlations between temperature and concentrations of NO\textsubscript{x} and CO

![Figure 4](image2.png)

**Figure 4.** Monthly-averaged concentrations of NO\textsubscript{x} and CO shown with relative humidity in the year 2016
3.4. Seasonal Variations of Temperature, Relative Humidity, NOx and CO Concentrations

Seasonal variability (in this case the relatively dry and wet seasons) is important to understand the influences of moisture in the atmosphere on pollutant concentrations. Relatively dry months are October, November, December, January and February and relatively wet months are March, April, May, June, July, August and September \[36\]. Figure 5 depicts how the concentrations of both gases change with temperature and relative humidity during relatively dry and wet seasons. As shown in the Figure 5, there is a difference between NOx concentration during relatively dry and wet seasons. The seasonal average air temperature in wet season is relatively lower than dry season. Since temperature and NOx concentrations are negatively correlated (however weak it may be), this must have resulted in increase of NOx concentration during the wet season. This is in agreement with Bathmanaban \[4\] work since they also obtained negative correlation between the temperature and NOx during the rainy season. CO exhibited only slightly small seasonal correlation with temperature. Both NOx and CO exhibited positive and negative seasonal correlations with relative humidity respectively. The concentrations of the two gases are also positively correlated.

![Figure 5](image)

Figure 5. Variability of seasonally-averaged concentrations of NOx and CO in the year 2016 and correlation with temperature (°C) and relative humidity (%) in relatively dry and wet seasons

4. Conclusions

Temperature and relative humidity is responsible for vertical mixing of atmospheric pollutants. They also responsible for different atmospheric stability conditions. Nitrogen oxides (NOx) and carbon monoxide (CO) are considered as air pollutants their concentrations are assumed to be influenced by temperature. More NOx concentration was observed during wet season compared to the dry season. There seems to be other sources of NOx during the rainy season on top of those emitted from vehicles or the reduction during the dry season could be due to better atmospheric mixing. The CO concentration did not show much change between wet and dry seasons. This can be due to relatively long residence time of this gas in the atmosphere. Temperature has impact on atmospheric mixing and that is the cause for the reduction of NOx as temperature increases. Both gases showed correlations with relative humidity, but at different rates during relatively wet and wet seasons. For NOx the dependence on relative humidity is stronger during wet season and that could also be the reason for the doubling of NOx concentration during wet season. CO correlation with relative humidity is relatively weak and the slopes are also small in both dry and wet seasons. The low dependence of CO on both temperature and relative humidity could be the reason for uniformity of the concentration of this gas during both seasons.

Finally, the authors suggest that in order to decrease the effects of air pollution in city the concerned body may be:

1. Import new vehicles with out tax or reduced tax, which burn fuel efficiently and reduce importing old vehic-
cles or appreciate and support machineries in the country (like Marathon Motor Engineering PLC and others).

(2) Participate and initiate green legacy campaign in Ethiopia and tree-planting in Addis Ababa (such as in Entoto Park, Sheger Project and others) and preserve them, which absorbs air pollutants in the city.

(3) Use vehicles appropriately such as use a less polluting and more fuel-efficient vehicles; drive at smooth accelerate and moderate speed; check up and made regular maintenance of vehicles and avoid unnecessary driving vehicles or drive less.

Acknowledgments

We would like to acknowledge the National Meteorology Agency Service of Ethiopia (NMASE), Addis Ababa Environmental Protection Authority (AAEPA), Central Pollution Control Board (CPCB) and Federal Transport Authority (FTA) for providing valuable information and data.

References


[34] Witz S, Moore AB. Effect of meteorology on the atmospheric concentrations of traffic-related pollutants at a Los Angeles site. JAPCA, 1981, 31: 1098-1101


ARTICLE
The Environmental Impact of Plastic Waste

Boyu Jiang1* Jiming Yu2 Yihang Liu3

1. Public health and Preventive Medicine, Health Inspection and Quarantine, North China University of Science and Technology, Tangshan, Hebei, 063210, China
2. Process Equipment and Control Engineering, University of Science and Technology Liaoning, Anshan, Liaoning, 114051, China
3. Preventive medicine, Public health and Preventive Medicine, North China University of Science and Technology, Tangshan, Hebei, 063210, China

ARTICLE INFO
Article history
Received: 1 September 2020
Accepted: 1 September 2020
Published Online: 30 September 2020

Keywords:
Multiple egression
Fuzzy hierarchy
Plastic waste
Environmental safety

ABSTRACT
The pollution caused by disposable plastic products is becoming more and more serious, and “plastic limit” has become a global consensus. This article mainly discusses the pollution problem from the following aspects: Integrate all relevant important indicators to establish a multiple regression model of the maximum amount of disposable plastic waste to estimate the maximum amount of disposable waste in the future without causing further damage to the environment; Establish an environmental safety level evaluation model and analyze the impact of plastic waste on environmental safety; Try to set the lowest level target that can be achieved by global waste at this stage, and conduct correlation analysis on the impact of humans, enterprises, and the environment; Select several countries based on their comprehensive strengths, conduct a comparative analysis of their plastic production, economic strength, and environment, and try to explore their responsibilities.

1. Introduction

Plastic is a commonly used material with huge social benefits. With the development of the world economy, the output of garbage around the world is also increasing rapidly, especially the use of plastic products is becoming more and more widespread, and disposable plastic are most commonly used in people’s lives. Disposable plastic products have brought convenience to people’s production and life, but due to the difficult degradation of plastic products, “white pollution” has become more and more serious. The large amount of disposable plastic products and the low recycling rate have caused serious pollution to the soil environment and the marine environment. The world is facing an environmental crisis caused by plastic waste. Currently, “Limiting plastic” has become a global consensus, and many countries and regions have launched actions to limit plastic and ban plastic. For example, in 2018, the European Parliament will...
issue a decree. Starting from 2021, the EU will completely prohibit member states from using 10 disposable plastic products such as drinking straws, cutlery and cotton swabs. A variety of disposable plastic products, including tableware and straw.

Therefore, in order to solve the problem of plastic waste, it is important to understand the current severity of plastic waste worldwide and mitigate the impact of plastic waste on the environment.

2. Assumptions and Symbols

2.1 Assumptions

(1) It is assumed that the moderate incineration of disposable plastic waste and proper treatment will not cause damage to the environment.

(2) It is assumed that all disposable plastic products produced each year are converted to waste.

(3) Assume no breakthrough in science and technology in the treatment of plastic waste.

2.2 Symbols

Here are the symbols and their meanings in this article:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
<td>Maximum amount of disposable plastic waste.</td>
</tr>
<tr>
<td>A</td>
<td>Recycling of disposable plastic waste.</td>
</tr>
<tr>
<td>B</td>
<td>Amount of incineration of disposable plastic waste.</td>
</tr>
<tr>
<td>Z</td>
<td>Environmental safety level.</td>
</tr>
<tr>
<td>M</td>
<td>Environmental safety level impact criteria.</td>
</tr>
<tr>
<td>N</td>
<td>Environmental safety level impact indicators.</td>
</tr>
<tr>
<td>E</td>
<td>Environmental safety level.</td>
</tr>
<tr>
<td>S</td>
<td>Environmental safety level score</td>
</tr>
<tr>
<td>P</td>
<td>Correlation coefficient.</td>
</tr>
</tbody>
</table>

3. Multiple Regression Model for Maximum Amount of Disposable Plastic Waste

3.1 Establishment of Maximum Amount Index Affecting Disposable Plastic Waste

First, we consider the factors that affect the maximum amount of disposable plastic waste, and consider the following three aspects from the sources of plastic waste, the way to deal with plastic waste, and the availability of resources for processing plastic waste.

From our collection of plastic use distribution data for various industries in 2015, packaging is the main use of disposable plastic, and more than 42% of plastic are used for packaging. At the same time, disposable consumer goods are the main source of disposable plastic. Such as disposable tableware, disposable straw and so on. Because of the excessive use and waste of disposable plastic, a large amount of disposable plastic waste has been accumulated. However, current treatment methods for disposable plastic waste are still relatively simple, including disposal, landfill, incineration, and recycling \(^1\). Among them, disposal of landfill and incineration is limited by disposal resources. For example, excessive land resources are used to discard plastic waste. Landfill, and the natural degradation of plastic in the soil takes hundreds of years, and it will cause serious “white pollution”, so land resources have certain restrictions on the landfill of plastic waste; meanwhile, incineration of plastic waste will Waste of petroleum resources. According to statistics, nearly 4% of the world’s petroleum resources are used for the incineration of plastic waste, and oil is a non-renewable resource. The global stock is not very optimistic. Therefore, petroleum resources are also a certain constraint on the incineration of plastic waste \(^2\).

In summary, under the premise of not causing further deterioration of the environment, we finally selected the amount of disposable plastic waste recovery, incineration, and resource constraints as indicators that affect the maximum amount of disposable plastic waste.
3.2 Establishment and Solution of Multiple Regression Model

Based on 3.1, we select the recovery rate, incineration rate, and resource constraints of disposable plastic waste as indicators that affect the maximum amount of disposable plastic waste, so as to establish a multiple regression model of the maximum amount of disposable plastic waste. The following equation:

\[ Y_{n+1} = \alpha A_n + \beta B_n - \gamma C_n \]  

Among them, \( Y_{n+1} \) is the maximum amount of disposable plastic waste in the following year, \( A_n \) is the recycled amount of disposable plastic waste in the year, \( B_n \) is the incinerated amount of disposable plastic waste in the year, and \( C_n \) is the resource (such as petroleum resources, petroleum resources, Environmental load, energy, etc.). \( \alpha \) and \( \beta \) are the regression coefficients of \( A_n \) and \( B_n \). \( \gamma \) is the limit coefficient of resources on the amount of recovery and incineration.

Based on the collected data, the regression coefficient is calculated using the least squares method as

\[ \alpha = 1.1404 \]
\[ \beta = 1.1404 \]

Through the regression test, the correlation coefficient of \( \alpha \) is \( R^2 = 0.9993 \), and the correlation coefficient of \( \beta \) is \( R^2 = 0.9997 \), both of which are close to 1, indicating that the correlation with \( Y \) is valid.

Because there are many influencing factors on the amount of resource restrictions, it is not possible to quantify and consider it at this time, so the forecast does not consider the amount of resource restrictions at this time. The regression coefficient is substituted into (1) to predict the maximum amount of disposable plastic waste in the future.

3.3 Model Result Analysis

According to Figure 2, under the prediction of the multivariate regression model of the maximum amount of disposable plastic waste, the maximum amount of disposable plastic waste that the environment can withstand is increasing year by year without further environmental damage, while the maximum amount of disposable plastic waste The increase is affected by the amount of incineration and recovery each year, because the amount of incineration and recovery has gradually increased since 1980, as shown in Figure 3.

![Figure 2. Multivariate regression model prediction charts for the maximum amount of disposable plastic waste (without resource restrictions)](image)

As of 2015, an estimated 55% of plastic waste worldwide have been discarded, 25% have been incinerated, and 20% have been recycled[2]. The discarded plastic waste will cause further damage to the environment. Therefore, the maximum amount of disposable plastic waste can only be assessed by changing the amount of incineration and recycling without further harming the environment. However, the amount of incineration will be controlled by petroleum resources. About 4% of the world’s petroleum resources are used in plastic incineration. If excessive use of petroleum resources, it will also cause the lack of petroleum resources and cause unnecessary troubles. At the same time, excessive incineration will also cause damage to the atmospheric environment; and the amount of recycling is controlled by the current level of science and technology. Advances in science and technology can enable more plastic waste to be recycled and reduce environmental damage. On the contrary, if the level of science and technology stagnates, it will also cause the recovery rate of plastic waste to stop growing, which will have a negative impact on the disposal of throwaway plastic waste[3]. Therefore, after considering resource constraints, it should be fixed in Figure 4.

![Figure 3. Estimated share of global plastic waste by disposal method](image)
4. DPSIR Environmental Safety Evaluation Model Based on F-AHP

4.1 Model Introduction

4.1.1 Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) combines qualitative description and quantitative analysis organically. This process adopts systematic planning and evaluation, and finally expresses and reflects complicated phenomena and decision thinking process systematically, modeled, and quantitatively. Through the analytic hierarchy process, researchers can analyze the research objects precisely and understand the relative major and minor influencing factors. The importance scale used in calculating the weight is shown in Table 1.

<table>
<thead>
<tr>
<th>Importance scale</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Both elements are equally important</td>
</tr>
<tr>
<td>3</td>
<td>The former is slightly more important than the latter</td>
</tr>
<tr>
<td>5</td>
<td>The former is clearly more important than the latter</td>
</tr>
<tr>
<td>7</td>
<td>The former is more important than the latter</td>
</tr>
<tr>
<td>9</td>
<td>The former is far more important than the latter</td>
</tr>
<tr>
<td>2,4,6,8</td>
<td>Intermediate values corresponding to a scale of 1-9</td>
</tr>
<tr>
<td>1/k,k=1,..9</td>
<td>The two elements are more important than the former</td>
</tr>
</tbody>
</table>

4.1.2 DPSIR Model

The DPSIR model is a conceptual model of the evaluation index system commonly used in environmental systems. It divides the evaluation index of natural systems into five types, including Driving Forces, Pressure, State, Impact and Responses. And each type is divided into several indicators\(^4\). We will use the DPSIR model as the research framework and the analytic hierarchy process as the carrier to establish an environmental safety index system, as showed in Figure 5.

![Figure 5. Index system diagram of environmental safety assessment](https://example.com/diagram.png)

4.1.3 Fuzzy Comprehensive Evaluation Method

The fuzzy comprehensive evaluation method is a systematic evaluation of the fuzzy phenomenon of possibility and uncertainty, that is, a fuzzy evaluation of the evaluation object, such as “good, better, average, worse, worse”, etc., is more important in fuzzy mathematics. The concept of membership, that is, the degree of membership, means the probability or degree of likelihood of the assessment\(^5\).

We consulted the literature and collected data to judge the 13 indicators of the selected countries. After establishing an evaluation index system and calculating the weight of each index, after consistency testing, the test formula is as follows.

\[
CI = \frac{\gamma_{\max} - 1}{n - 1}
\]

Evaluate the country’s level of environmental safety according to four levels: very safe, safe, more dangerous, and dangerous.

4.2 Establishment and Solution of Environmental Safety Evaluation Model

Through our literature review and data collection, we learned that in the 2018 Global Environmental Performance Index (EPI) ranking released by Yale University in

\[DOI: https://doi.org/10.30564/jees.v2i2.2340\]
the United States, Australia ranked first in many scoring items and ranked first overall, so Australia Known as the “most suitable area for human habitation”, we chose Australia as the best level of environmental safety.

At the same time, China is the largest developing country in the world. In recent years, China has played an important role in the development of the world economy. However, China’s environmental security level is not very optimistic. Therefore, we chose China as the research object to analyze China and environmental security. The best level is the gap between Australia.

4.2.1 Establishment and Solution of AHP Model

(1) According to the analysis, the following matrix is obtained:

\[
Z = \begin{bmatrix}
1 & 1/2 & 1/4 & 1/5 & 1/3 \\
2 & 1/3 & 1/4 & 1/2 & 1 \\
3 & 1 & 1/2 & 2 & 1 \\
4 & 4/5 & 2 & 1 & 3 \\
5 & 2 & 1/2 & 1/3 & 1 \\
\end{bmatrix}
\]

\[
M_1 = \begin{bmatrix}
1 & 3 & 2 \\
1/2 & 1/3 & 1/2 \\
\end{bmatrix}
\]

\[
M_2 = \begin{bmatrix}
1/2 & 1 \\
\end{bmatrix}
\]

\[
M_3 = \begin{bmatrix}
1 & 3 & 2 \\
1/3 & 1 & 1/2 \\
\end{bmatrix}
\]

\[
M_4 = \begin{bmatrix}
1/2 & 1 \\
\end{bmatrix}
\]

\[
M_5 = \begin{bmatrix}
1/2 & 2 \\
1/2 & 1 \\
\end{bmatrix}
\]

(2) Indicator weight calculation

The weight of each indicator is determined according to the basic method of the analytic hierarchy process, and the weight of the first-level indicator obtained is:

\[
(M_1, M_2, M_3, M_4, M_5, M_6) = (0.0624, 0.0986, 0.2618, 0.4161, 0.1611)
\]

The weight of the secondary indicator is

\[
(N_1, N_2, N_3, N_4, N_5, N_6, N_7, N_8, N_9, N_{10}, N_{11}, N_{12}, N_{13}) = (0.2771, 0.4658, 0.1611, 0.0960)
\]

All the above judgment matrices have passed the consistency check, so the ownership reassignment is satisfactory. As shown in table 2.

<table>
<thead>
<tr>
<th>Index</th>
<th>N_1</th>
<th>N_2</th>
<th>N_3</th>
<th>N_4</th>
<th>N_5</th>
<th>N_6</th>
<th>N_7</th>
<th>N_8</th>
<th>N_9</th>
<th>N_{10}</th>
<th>N_{11}</th>
<th>N_{12}</th>
<th>N_{13}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>0.0173</td>
<td>0.0291</td>
<td>0.101</td>
<td>0.0060</td>
<td>0.6557</td>
<td>0.0329</td>
<td>0.1411</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4.2.2 Solution of Fuzzy Comprehensive Evaluation Method

(1) Establish a set of evaluation indicators.

\[
N = (N_1, N_2, N_3, N_4, N_5, N_6, N_7, N_8, N_9, N_{10}, N_{11}, N_{12}, N_{13}) = (\text{Economy, technology, ... , existing policies and implementation})
\]

(2) Create a Judging Set

\[
E = (E_1, E_2, E_3, E_4) = (\text{very safe, safe, less secure and dangerous})
\]

(3) We judged 13 indicators in Australia and China by consulting the literature and collecting data.

(4) Establish a single factor evaluation matrix R.

\[
R = (r_{ij})_{13 \times 4}
\]

Using the weights obtained by the analytic hierarchy process as the weight vector of the fuzzy comprehensive evaluation index, the different weights of Australia and China in the four levels of very safe, safe, less secure and dangerous can be obtained through calculation, that is Table 3.

Table 3. Comprehensive weight table of Australian and Chinese environmental safety levels

<table>
<thead>
<tr>
<th>Environmental safety level</th>
<th>very safe</th>
<th>safe</th>
<th>less secure</th>
<th>dangerous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australian comprehensive weight.</td>
<td>0.5515</td>
<td>0.2711</td>
<td>0.1269</td>
<td>0.0508</td>
</tr>
<tr>
<td>Chinese comprehensive weight.</td>
<td>0.2035</td>
<td>0.3274</td>
<td>0.3117</td>
<td>0.1576</td>
</tr>
</tbody>
</table>

Finally, we define the score, (very safe, safe, less secure and dangerous)=(4, 3, 2, 1), Substitute the comprehensive weights of Australian and Chinese environmental safety levels in Table 3 to get the final scores of the two countries.

\[
S_1 = 3.3237 \\
S_2 = 2.5773
\]

DOI: https://doi.org/10.30564/jees.v2i2.2340
4.3 Model result analysis

Australia’s final environmental safety rating is 3.3237, which is at a safe level, and China’s final environmental safety rating is 2.5773, which is at a relatively dangerous level. From this comparison, we can see that there is still a certain gap between China and the environmental safety level.

It can be seen from the matrix listed above that China’s environmental safety level is significantly different from Australia’s in various aspects. Because this article mainly discusses the impact of plastic waste on environmental safety, we will only focus on plastic waste. Analyze the gap between China and Australia and how to close it.

**Table 4. Comparison of Australian and Chinese plastic waste (2010)**

<table>
<thead>
<tr>
<th>Index</th>
<th>Total plastic waste output (million tonnes)</th>
<th>World share of underdetected plastic waste</th>
<th>Plastic waste entering the ocean (million tonnes)</th>
<th>Plastic waste per capita (kg per person per day)</th>
<th>Improper waste management in countries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>0.9</td>
<td>0%</td>
<td>0.01–0.25</td>
<td>0.112</td>
<td>0.04%</td>
</tr>
<tr>
<td>China</td>
<td>59.08</td>
<td>74%</td>
<td>&gt;5.00</td>
<td>0.121</td>
<td>27.7%</td>
</tr>
</tbody>
</table>

From Table 4, China has a huge gap in Australia in terms of total plastic waste production, inadequately treated plastic waste, plastic waste entering the ocean, and improperly managed waste.

From an economic point of view, as a developing country, China’s economic development has enabled various industries to choose plastic products that are widely used, easy to process, and inexpensive under the principle of maximizing economic benefits. Increasing demand has led to the rapid development of the plastic manufacturing industry, so the output of plastic waste is huge.

From a technical perspective, in 1921, China began to industrialize plastic plastic products. Scientists are constantly searching for new plastics manufacturing technology, and globalization has enabled the technology to be exchanged and improved in various countries, making the production and widespread use of plastic possible.

In terms of consumption, economic development has increased consumption and increased domestic demand, and people’s daily consumption has also promoted the development of the plastics industry. Consumers have a tendency to choose convenient plastic bags when shopping for neat and clean product packaging. Because of its strong corrosion resistance, durable, waterproof, lightweight, and easy to shape, plastic has been the first choice for packaging materials in the express delivery and takeaway industries. The emergence of e-commerce and food delivery has dramatically increased the demand for plastic, which has greatly promoted the development of the plastics industry.

In terms of policy and implementation, the Chinese government issued a “plastic restriction order” in 2007, which clearly stipulates that the production, sale, and use of plastic shopping bags with a thickness of less than 0.025 mm are nationwide; in all supermarkets, shopping malls, and trade fairs The market and other commodity retail establishments implement a system of paid use of plastic shopping bags. Plastic shopping bags are not permitted to be provided free of charge. Although China proposed the policy of restricting the use of plastic very early, there were problems in the implementation. In the early stage of implementation of the Plastic Restriction Order, the effect was very significant. However, with the development of the time, there has been a saying that Plastic Restriction makes the name exist. The “white pollution” is not simply disappeared, but has become increasingly widespread. Depending on statistics, from 2008 to 2015, the consumption of plastic bags in China’s express delivery industry increased from 8.268 billion to about 14.7 billion.

Therefore, China needs to solve the problem in terms of people’s environmental awareness, technical methods for processing plastic waste, and implementation of policies that restrict the use of plastic. It must pay more attention to reducing the gap with environmental safety.

5. Relevance to Minimum Levels of Goals and Impact

5.1 Set Minimum Goals

In order to eliminate plastic waste and minimize the negative impact of plastic waste on the environment and human beings, we plan to set a goal at the lowest level at this stage.

In an ideal state, we hope that the annual output of plastic waste is zero, that is, no more plastic waste is produced every year, and humans no longer use any single-use or disposable plastic products. The plastic waste generated can be fully recycled, and plastic waste will not be recycled. Any negative impact on the environment, society and humanity.

However, it is clear that at the current stage of human science and technology or economic level, the ideal state cannot be achieved. At this stage, human beings still need a large number of plastic products. Some plastic products cannot be replaced by other substitutes, such as used in plastic products in packaging, construction or other fields, as showed in Figure 6

They have the irreplaceable advantages in various fields, and the generation of some non-recyclable plastic waste cannot prevent that. Therefore, we have to find the
amount of non-recyclable plastic waste in the world at this stage as the minimum level of plastic waste at this stage. It can be consulted on Figure 3 Estimated share of global plastic waste by disposal method in 3.3. As of 2015, it is estimated that 55% of plastic waste worldwide is discarded, 25% are incinerated, and 20% are recycled. Among them, 80% of plastic waste discards and incinerated. According to collect data, the output of plastic waste in 2015 was about 302 million tons.

In the end, through calculation, we set a minimum level of disposable plastic waste at the current stage of 241.6 million tons.

5.2 Correlation Analysis

When the world reaches the minimum level of plastic waste at this stage, we will discuss the impact from three aspects: human, business, and the environment. In terms of impacts on humans, we consider the impact of plastic production on average consumption levels; in terms of impacts on enterprises, we consider the impact of plastic production on the operating profit of plastic enterprises; in terms of environmental impact, we consider the impact of plastic production on Impact of Environmental Performance Index (EPI).

We select China as the research object of this problem and collect relevant data. As shown in Table 5:

<table>
<thead>
<tr>
<th>Year</th>
<th>Per capita annual consumption level / yuan</th>
<th>Annual profit of the plastics industry / yuan</th>
<th>EPI</th>
<th>Plastic production / 10,000 tons</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>14699</td>
<td>0.96×10^{11}</td>
<td>42.24</td>
<td>2730.3</td>
</tr>
<tr>
<td>2013</td>
<td>16190</td>
<td>1.12×10^{11}</td>
<td>6878.8</td>
<td>7485.8</td>
</tr>
<tr>
<td>2014</td>
<td>17778</td>
<td>1.18×10^{11}</td>
<td>43</td>
<td>7860.7</td>
</tr>
<tr>
<td>2015</td>
<td>19397</td>
<td>1.20×10^{11}</td>
<td>65.1</td>
<td>7267.5</td>
</tr>
<tr>
<td>2016</td>
<td>21285</td>
<td>1.29×10^{11}</td>
<td>7515.5</td>
<td></td>
</tr>
<tr>
<td>2017</td>
<td>22902</td>
<td>1.35×10^{11}</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

We calculate the correlation coefficient P between China’s per capita annual consumption level, the annual operating profit of the plastic industry, and EPI and China’s plastic output.

Pearson correlation coefficient (Pearson Correlation Coefficient) is used to measure whether two data sets are on a line. It is used to measure the linear relationship between distance variables, that is, the correlation strength. The formula is as follows:

\[
P_{xy} = \frac{\cos(x'y')}{\sigma_x \sigma_y} = \frac{E((x-X)(y-Y))}{\sigma_x \sigma_y} = \frac{E(x'y')}{\sigma_x \sigma_y} = \frac{E(y')}{\sigma_y} \cos(x'y')
\]

Correlation coefficients of the three are obtained through calculation

\[P_1=0.681 \]
\[P_2=0.824 \]
\[P_3=0.472 \]

All the per capita consumption and plastic production showed significant significance. The correlation coefficient value was 0.681, ranging from 0.6-0.8, showing a strong correlation, and the correlation coefficient value was greater than 0, meaning that there was a positive correlation between per capita consumption and plastic production.

The plastic industry’s operating profit and plastic output all show significant significance. The correlation coefficient value is 0.824, which is between 0.8-1.0, showing a strong correlation, and the correlation coefficient value is greater than 0, which means the plastic industry’s operating profit there is a positive correlation with plastic production.

The correlation coefficient value between EPI and plastic output is 0.472, ranging from 0.4 to 0.6, which is moderately correlated, and the correlation coefficient value is greater than 0, which means that there is a definite correlation between EPI and plastic output.

After calculation of the correlation coefficient, it was found that the plastic output has the greatest impact on the
plastic industry, with a correlation coefficient of 0.824, because plastics are commonly used in building materials and engineering products. They have excellent performance and low cost, and are the best choice for basic materials of industrial enterprises. The demand for plastic in the commercial and industrial fields also promotes the rapid development of the plastics industry, which can occupy an important position in the light industry. Therefore, when we achieve the objective of the lowest level of waste, the plastics industry will be greatly impacted. There will be a big gap in profits. At the same time, the plastic industry will also face the opportunity to reform technology and seek breakthroughs.

The impact of plastic output on per capita consumption levels is also strong, with a correlation coefficient of 0.681, because economic development has increased consumption and increased domestic demand, and people’s daily consumption has also promoted the development of the plastic industry. Consumers tend to choose convenient plastic bags when shopping for neat and clean product packaging. Because of its durable corrosion resistance, durable, waterproof, lightweight, and easy to shape, plastic has become the first choice for packaging materials in the express delivery and takeaway industries. The emergence of e-commerce and food delivery has dramatically increased the demand for plastic, which has greatly promoted the development of the plastics industry. Therefore, when we achieve the objective of the lowest level of waste, the level of per capita consumption may decline to some extent.

The impact of plastic production on EPI is relatively general, with a correlation coefficient of 0.472, because EPI uses 10 policy categories and 25 environmental indicators for evaluation, and the “white pollution” caused by plastic waste is part of all environmental pollution, and there is a certain Relevance, but it didn’t play a vital role. Therefore, when we achieve the goal of the lowest level of waste, the EPI will increase to a certain extent and will not be particularly affected.

6. Fairness of the Global Environmental Crisis

Depending on the data on income levels of countries in the world provided by the World Bank\textsuperscript{[9]}, select high-income countries-Australia, high- and middle-income countries-China, low- and middle-income countries-India, and low-income countries-Guinea. The proportion of improperly managed plastic waste, the amount of plastic waste per capita, and national plastic consumption are used as reference indicators. Table 6 is generated to analyze the fairness of the global environmental crisis.

<table>
<thead>
<tr>
<th>Country</th>
<th>GDP per capita ($)</th>
<th>EPI</th>
<th>Percentage of mismanaged plastic waste</th>
<th>Per capita amount of plastic waste generated (kg)</th>
<th>Plastic consumption (million tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>57200</td>
<td>65.7</td>
<td>0%</td>
<td>0.11</td>
<td>16.5</td>
</tr>
<tr>
<td>China</td>
<td>9770</td>
<td>49</td>
<td>74%</td>
<td>0.12</td>
<td>80</td>
</tr>
<tr>
<td>India</td>
<td>2010</td>
<td>48.3</td>
<td>85%</td>
<td>0.01</td>
<td>14.56</td>
</tr>
<tr>
<td>Guinea</td>
<td>880</td>
<td>44.4</td>
<td>84%</td>
<td>0.03</td>
<td>0.27</td>
</tr>
</tbody>
</table>

Comparing the indicators of Australia, China, India and Guinea, we get Figure 7:

**Figure 7. Comparison chart of indicators in Australia, China, India and Guinea**

Australia is a developed country with high per capita GDP, leading productivity level, high level of industrialization, and high level of national education. Therefore, the amount of plastic waste per capita is high, but the EPI is high, and the proportion of plastic waste management is extremely high. The emphasis on wasting management has led to high national environmental performance.

China and India are at the same time developing countries, and they are ranked one or two in the world’s population. The difference in EPI is small. China’s industrialization level is higher than India, and plastic consumption is significantly higher than India. With the continuous improvement of industrialization level and people’s living the level of plastic waste per capita in China is constantly improving. Although the proportion of improperly managed plastic waste in China is still astronomical, it is observed that the proportion of plastic waste in China is lower than that in India and Guinea. It can be seen that China’s management of plastic waste is effective. But there is still plenty of room for further improvement.

Guinea is located in Africa, its productivity is lagging, its economy is dominated by agriculture and mining, its industrial base is weak, plastic consumption is low, and the amount of plastic waste per capita is small, but the
proportion of improperly managed plastic waste is high, reflecting the great expectations Control.

To ensure the fairness of countries in the global environmental crisis, the following solutions are recommended:

Each country signed a plastic waste management agreement, imposed restrictions on the country’s plastic production and plastic waste volume, strengthened the research and development and productivity of plastic alternatives, and implemented strong single-use or disposable plastic control policies within the country. As developed countries have reached the current high level, they have completed the process of industrialization and achieved primitive accumulation, but in the process have caused irreversible damage to the environment. Therefore, compared with developing countries, developed countries Higher responsibilities and obligations should be assumed. Developed countries should provide technical, equipment, and financial assistance to countries with low productivity, so that countries with low productivity can realize the industrialization process as soon as possible, and help them minimize the production and use of disposable plastic. At the same time, with the help of developed countries, developing countries should strive to improve the production process of plastic and the process of waste disposal, and improve the level of national waste management.

7. Strengths and Weaknesses

7.1 Strengths

(1) In the multivariate regression model of the maximum amount of disposable plastic waste, the constraints of resources on recycling and incineration have been fully considered, making the model more comprehensive.

(2) An evaluation method that uses DPSIR as an indicator and combines the analytic hierarchy process and fuzzy comprehensive evaluation method, making full use of the advantages of the two methods, the weighting is reasonable, the calculation is relatively simple, and it has certain advantages and reliability.

(3) In the impact analysis of plastic waste, the correlation is used to determine the magnitude of the impact with the strength of the correlation, making the analysis more concrete and concrete.

7.2 Weaknesses

(1) No consideration of the impact of plastic alternatives on model results.

(2) The fuzzy analytic hierarchy process has certain subjectivity when determining the weight of the index, and lacks scientific and objective evaluation.

8. Conclusions

(1) The multiple regression model was used to estimate the maximum amount of plastic waste in the environmental carrying range, and the factors affecting the maximum amount of plastic waste were analyzed from three aspects: the source of the plastic waste, the current severity, and the treatment method.

(2) Select Australia and China, use Australian environmental quality as the environmental safety level standard, and use the DPSIR environmental safety evaluation model based on fuzzy analytic analysis to score the two countries, with score of 3.3237 and 2.5773, respectively. It analyzes the gap between China and Australia on the level of environmental safety.

(3) On the basis of the multiple regression model of question 1, set the current minimum level of global waste that can be reached at 241.6 million tons per year, and through correlation analysis, get the plastic output to humans, enterprises, and the environment. The correlation coefficients are 0.681, 0.824, and 0.472, respectively.

(4) Select four high-income, high-middle-income, low-middle-income, and low-income countries, Australia, China, India, and Guinea, and analyze the gaps between the four countries’ plastic waste issues through various data comparisons and propose reasonable solutions Solution: Developed countries should give developing countries some support and assume the responsibilities of big countries in the global plastic crisis.

Expectations and Recommendations for Future Global Disposable Plastic Waste

First, We analyzed the basic situation of global disposable plastic waste at the current stage by consulting the literature and collecting data. Since 1950, the global plastic output has grown rapidly. As of 2015, the annual global plastic output has increased by nearly 200 times, reaching 381 million tons. When the global plastic output is increasing rapidly, the global plastic waste is also increasing rapidly. By 2015, 5.8 billion tons of plastic wastes have been accumulated, and only 9% of it has been recycled. These accumulated plastic wastes have produced a global environment. Serious damage.

Then, we comprehensively considered the sources, severity, and treatment of unnatural waste, and established a multiple regression model to predict the maximum amount of plastic waste that the environment can withstand in the future. When the maximum amount is reached, the global environment will no longer be Being further these lands filled plastic waste can be safely reduced. Then, according to this model, we also found the lowest level of global
plastic waste at the contemporary stage, which is 241.6 million tons. We take it as our goal at this stage. In order to predict the specific time when the global target will be reached at the current stage, we made a simple predication of the global plastic waste recovery rate, incineration rate and discard rate, as showed in the figure:

It can be seen from the forecast chart that before 1980, the recycling and incineration of plastic were negligible, so 100% were discarded. Starting from incineration in 1980 and recycling in 1990, the garbage recovery rate has risen by an average of about 0.7% per year. As of 2015, an estimated 55% of plastic waste worldwide have been discarded, 25% have been incinerated, and 20% have been recycled. After a straightforward prediction, we can see that by 2050, the incineration rate will be increased to 50%; the recovery rate will be 44%; and the discarded waste will be reduced to 6%. According to this forecast chart, we predict the amount of global plastic waste in the future, and get:

It is predicted that by 2078, the amount of plastic waste worldwide could be reduced to 241.6 million tons, reaching the minimum level of our target.

Finally, we make a timetable:

<table>
<thead>
<tr>
<th>TIME</th>
<th>Predicted Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>2019</td>
<td>Drop rate is below 50%</td>
</tr>
<tr>
<td>2029</td>
<td>Incineration rate = Discard rate</td>
</tr>
<tr>
<td>2032</td>
<td>Recovery rate = Discard rate</td>
</tr>
<tr>
<td>2078</td>
<td>Meet the expected minimum level</td>
</tr>
</tbody>
</table>

Of course, this is only a reasonable prediction under our assumptions, and in the real world, there are numerous factors that will accelerate or hinder the realization of our goals. For example, more and more national governments have promulgated policies that restrict the use of plastic and even ban plastic, which will accelerate the achievement of our goals to a certain extent. Similarly, the development of science and technology in the future may lead to the emergence of better plastic alternatives, New breakthroughs have been achieved in the treatment of plastic waste. On the contrary, some factors will hinder the progress of our goals. For example, the economic crisis will greatly inhibit the development of many enterprises, including the plastic industry. Of course, it will also limit the consumption level of the people and reduce the purchasing power. Obstacles in the same way, as well as the outbreak of war, climate change and other factors will also hinder the realization of our planned goals to a certain extent.

References

ARTICLE
Sustainability Assessment of the Groundwater Quality in the Khoyrasole Block, Birbhum District, West Bengal to Achieve Rural Water Security

S. K. Nag* Shreya Das
Department of Geological Sciences, Jadavpur University, Kolkata-700032, India

ARTICLE INFO

Article history
Received: 20 October 2020
Accepted: 16 November 2020
Published Online: 30 December 2020

Keywords:
Water security
Groundwater assessment
Groundwater quality
India

ABSTRACT

In order to attain the water security goal, specifically in highly developing areas, delineation of pure and sustainable water resources is of utmost priority. In the present study, a preliminary investigation of the groundwater chemistry was carried out. This was followed by assessing the suitability of groundwater to be used as an alternative and reliable resource for public use in the Khoyrasole block, Birbhum district, India. Altogether 15(fifteen) samples of groundwater, were collected from bore wells spread well over the Khoyrasole block have been considered. After completing the chemical analysis of the groundwater samples, the study revealed the quality of groundwater. The spatial distribution of groundwater quality parameters such as pH, Total Dissolved solids (TDS), Hardness, Calcium, Magnesium, Sodium, Potassium, Iron, Chloride, Carbonate, Bicarbonate, Sulphate, Nitrate and Fluoride have also been studied. High to very high levels of iron and fluoride have been observed to be present in 67% and 53% of the samples respectively. Based upon the calculated parameters like SAR, MAR, PI and Chloro Alkaline Indices, groundwater of Khoyrasole block is majorly suitable for the purpose of agriculture and irrigation. Plotting of ionic scatter plots and geochemical facies also indicate the water samples to be of “fresh water” category, with no dominant cation or anion playing a selectively dominant role in influencing the groundwater chemistry in the study area.

1. Introduction

The human race, for its day to day sustenance on mother Earth, makes exhaustive use of all the available vital natural resources. Over the last few decades, exponential growth in population, expansion of urban areas, discovery of cutting edge technology and above all an indifferent attitude of the human race has taken a toll on the environment. Various natural resources available in moderate quantities have already been used up and many more are on the verge of depletion. With no viable option of being able to redeem these naturally available reserves, it is high time we understand the importance of sustainable development and behave accordingly. Amongst the natural resources available, water, undoubtedly is a prime necessity for one and all and is the most sought after in almost all sectors. Water is available

*Corresponding Author:
S. K. Nag,
Department of Geological Sciences, Jadavpur University, Kolkata-700032, India;
Email: sisirknag@gmail.com
to us in more than one form or type such as ice, vapour and water - the last being of two types - saline and fresh water. Out of the total amount of water present in this globe, a very small fraction only (~2.4%) is occurring on the main land, and only a small portion of this amount is available for using as fresh water. Thus the available fresh water to human being is only a small fraction (~0.3% - 0.5%) of the total water available on the earth. This compels us to be judicious in use of this natural resource [1]. The quantity of fresh water is a finite and limited resource [2].

The utilization of water from very early days has led to its over exploitation coupled with the growing population along with improved standard of living as a consequence of technological innovations [3,4]. Thus contamination of groundwater is not away from the evils of modernization. As a result, quality of groundwater is deteriorating at a faster pace due to pollution ranging from septic tanks [5,6], land fill leachates, domestic sewage [7-9] and agricultural run - off / agricultural fields [10-14] and industrial wastes [15]. Contamination of groundwater also depends on the geology of the area and it is rapid in hard rock areas especially in limestone regions where extensive cavern systems are below the water table [16]. This is a common feature, not only in developed countries but also in developing countries like India. The changes in quality of groundwater response to variation in physical, chemical and biological environments through which it passes [17]. Groundwater quality is a very sensitive issue and it transcends national boundaries and the present study focuses on the quality and contamination of groundwater, the availability of which is the key to day to day livelihood. Quality of water from groundwater reserves is dynamic in nature as they are affected by various human activities, including the expansion of cultivated and irrigated lands, industrialization, urbanization and others. Due to the fact that it is the largest available source of fresh water lying beneath the ground, not only delineation of groundwater potential zones has become crucial, but also monitoring and conserving this important resource is equally prior. Groundwater is usually clear, colourless and remains relatively at constant temperature, and is therefore normally superior to surface water with regard to sanitary considerations. Utilization of groundwater as drinking water is a large scale practice especially in the semi-urban and rural parts of our country. Although India has made some progress in implementation of potable supply of water but gross disparity still exists in the country in terms of coverage area. A major part of India is comprised of semi - urban and rural areas and in these parts there still exist towns and villages, where well managed water transport systems like piped distribution of water and related infrastructures are either not available or not fully functional. Hence almost 70% of the population in India consumes groundwater for drinking on a daily basis, not by choice but by compulsion [18].

India is heading towards a freshwater crisis [19] mainly due to improper management of water resources and environmental degradation. The outcomes of this crisis are already evident in many parts of India, varying in scale and intensity depending on the time and season of the year [20]. Groundwater contains salt in higher proportion compared to surface water due to its slow movement and higher residence period which ultimately is responsible for increase in the soluble mineral content in water. Water acts as a universal solvent and also carries minerals in solution may be in small quantity, but this determines its suitability for different purposes. Groundwater quality is different in different places and also in different stratum. It is also variable from season to season. The necessity of water quality for different purposes (e.g., drinking water, industrial water and irrigation water) varies widely. In present scenario, groundwater quality is equally important as its quantity [21,22]. In the present study quality of water w.r.t consumption has been assessed along with determination of hydrogeochemical evolution of parameters.

2. Study Area

The community development block Khoyrasole (Figure 1) lies in the Suri Sadar sub division of Birbhum district. The geographical area of the district is 499 sq-kms. The north-western part of the district, particularly Rampurhat - Nalhati blocks, the contours are above 110m - 140m (MSL) while it comes down to 60-70m in eastern and south eastern part around Khoyrasole - Rajnagar - Suri blocks where topography is almost flat. The Lower Gondwana Barakar Formation occurs with pronounced unconformity over the Archeans and has faulted boundaries with Archean comprising leucocratic gneisses at Rajnagar - Khoyrasole. The ground mass comprises pebbly to coarse grained white feldspathic ferrigenous sandstone, grey carbonaceous shale and coal. In Birbhum, groundwater occurs under both water table condition in the near surface aquifers and under confined condition in deeper aquifers. The western part of the district around Khoyrasole, Dubrajpur, Rajnagar and Suri, west of Rampurhat and Nalhati area is underlain by hard rocks, which vary from basaltic (Rajmahal volcanics) rocks in the north and granite, gneisses and schists in the south. The weathered zone of the hard rocks forms the main repository of ground water in the area under study. In the eastern fringe of Khoyrasole, Dubrajpur, Rajnagar, sediments of Gondwana Super Group form the main repository of groundwater at deeper level. Lateritic soil also forms the groundwater source in
parts of Suri, Md.Bazar, and further east.

Khoyrasole lies between 23°42’ and 23°54’ N latitudes and 87°05’ and 87°22’ E longitudes. This block has been mapped on Topo Sheet nos. 73M/1, 73M/5 and 73M/6 (Figure 1). Three rivers, namely Sal, Hinglo and Ajay pass through this block. Sal flows along the northern side of Khoyrasole whereas Ajay forms the southern boundary of the block. This river also forms the boundary between Birbhum and Bardhaman districts. River Hinglo lies midway between Sal and Ajay. In summer time, the climate of the area becomes hot and dry with temperatures rising up to 40° C and above, whereas in winter, the temperature goes down to 10° C or below. Moderate to high rainfall is experienced in the district, during the monsoon season.

3. Methodology

The field investigation was carried out during post monsoon period in December 2019. Groundwater samples were taken from 15 bore wells distributed homogeneously around the investigated area. Figure 1 below presents the location map of sampling points in the study area. The locations from where groundwater samples were collected have been pre-determined so as to spread over the entire area with due attention in areas expected for contamination.

Parameters such as, pH, Electrical Conductivity (EC) and Total Dissolved Solids (TDS) of water samples have been measured on spot using the potable HI 98130 Combo pH / EC / TDS / Temperature meter by Hanna Instruments. Before recording the values, calibrations were done using 4.01, 7.01 and 10.01 buffer solutions for pH and 12.33 mS/cm buffer solution for electrical conductivity readings. Water samples were collected and stored at moderate temperatures before carrying out chemical analysis. Before collection, the bore wells were pumped for a few times and the bottles were rinsed well for 2-3 times. Each sample has been collected in polyethylene 1,000 ml bottle after washing it thoroughly by acid. The bottle was filled completely with water and utmost care was taken so that no air bubble remains trapped within the water sample. The sample bottles have been sealed with the double plastic caps to circumvent evaporation. During transferring the collected samples to the laboratory for chemical analyses, precautions were also taken to keep the samples away from stirring. Analyses of the water samples have been performed immediately after transferring the sample bottles to the laboratory for major ions by employing standard methods [23].

Figure 1. Map showing study area and locations of sampling points

DOI: https://doi.org/10.30564/jees.v2i2.2479
Survey of India (SoI) Topo sheets numbered 73 M/1, 73 M/5 and 73 M/6 of 1:50,000 scale and Satellite imagery (IRS-IB, LISS-II) have been used to prepare the fundamental map where locations of investigating points have been clearly demarcated. To delineate the boundaries of geological formations and fault lines, the GIS based image processing software TNT Mips 2012 has been used. Concentrations of cations along with fluoride in water samples were determined with an Atomic Absorption Spectrophotometer with a specific lamp for each of the particular elements. Average values of three replicates were taken for each determination. The flow chart (Figure 2) represents the entire methodology adopted.

4. Results and Discussions

4.1 Groundwater Chemistry

For evaluation of the groundwater quality in general the parameters considered for study and evaluated have been presented in Table 1. Table 2 presents the permissible limits of the analysed parameters along with percentage of samples missing the mark regarding the same. Among the parameters tested in situ - pH, Electrical Conductivity (EC) and Total Dissolved Solids (TDS) both pH and TDS where found to have minimum, maximum and average values within the desirable/ permissible guidelines of WHO.24 pH ranges from 6.89-7.59 with an average of 7.33 whereas TDS ranges from 221.5-896.6 mg/l with an average of 430.31 mg/l. In case of EC, 3 samples were found to have values beyond the permissible limit but the average value was contained well within the WHO guideline.

Table 1. Statistical Summary of Physico-chemical Parameters Analysed

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Median</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>6.89</td>
<td>7.59</td>
<td>7.33</td>
<td>7.36</td>
<td>0.22</td>
</tr>
<tr>
<td>EC</td>
<td>110</td>
<td>2200</td>
<td>600.67</td>
<td>320.0</td>
<td>593.77</td>
</tr>
<tr>
<td>TDS</td>
<td>221.5</td>
<td>896.6</td>
<td>430.31</td>
<td>354.5</td>
<td>195.06</td>
</tr>
<tr>
<td>Hardness</td>
<td>121.52</td>
<td>509.6</td>
<td>250.43</td>
<td>219.52</td>
<td>111.56</td>
</tr>
<tr>
<td>Calcium</td>
<td>18.46</td>
<td>112.3</td>
<td>53.94</td>
<td>50.79</td>
<td>28.37</td>
</tr>
<tr>
<td>Magnesium</td>
<td>10.1</td>
<td>141.57</td>
<td>37.34</td>
<td>32.3</td>
<td>31.97</td>
</tr>
<tr>
<td>Sodium</td>
<td>16.75</td>
<td>65.41</td>
<td>36.46</td>
<td>37.83</td>
<td>14.77</td>
</tr>
<tr>
<td>Potassium</td>
<td>1</td>
<td>4.65</td>
<td>1.94</td>
<td>1.53</td>
<td>1.02</td>
</tr>
<tr>
<td>Iron</td>
<td>&lt;0.02</td>
<td>35.8</td>
<td>3.24</td>
<td>2.8</td>
<td>11.09</td>
</tr>
<tr>
<td>Chloride</td>
<td>9.7</td>
<td>190.12</td>
<td>46.82</td>
<td>19.4</td>
<td>55.78</td>
</tr>
<tr>
<td>Carbonate</td>
<td>12.4</td>
<td>28.8</td>
<td>20.14</td>
<td>17.85</td>
<td>4.92</td>
</tr>
<tr>
<td>Bicarbonate</td>
<td>84.84</td>
<td>398.9</td>
<td>195.9</td>
<td>188.98</td>
<td>85.84</td>
</tr>
<tr>
<td>Sulphate</td>
<td>0.96</td>
<td>24.65</td>
<td>10.95</td>
<td>9.56</td>
<td>7.78</td>
</tr>
<tr>
<td>Nitrate</td>
<td>3.29</td>
<td>21.32</td>
<td>11.54</td>
<td>10.77</td>
<td>4.64</td>
</tr>
<tr>
<td>Fluoride</td>
<td>0.96</td>
<td>4.75</td>
<td>2.04</td>
<td>1.52</td>
<td>1.16</td>
</tr>
</tbody>
</table>
The cationic abundance in the groundwater of Khoyrasole followed the pattern: $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{Fe} > \text{K}^+$. Though the abundance shows average value of iron to be behind three other major cations but almost 67% of the samples (10 out of 15) contain iron way above the permissible limit of 0.3 mg/l. The average value of iron, 3.24 mg/l in groundwater of Khoyrasole is thus almost 10 times above the prescribed limit. The highest concentration of iron in the study area has been found to be 35.8 mg/l which is 100 times the permissible limit and hence is of immense concern. Concentrations of iron in higher proportion is found to occur in groundwater if pyrite bearing rock is found to be exposed to oxygenated water. It is also found when ferric oxide or hydroxide minerals are in contact with reducing substances.[25]

The anionic abundance pattern in groundwater of Khoyrasole is as follows: $\text{HCO}_3^- > \text{Cl}^- > \text{CO}_3^{2-} > \text{NO}_3^- > \text{SO}_4^{2-} > \text{F}^-$. In case of the anions as well all the parameters except fluoride have concentrations within the permissible limits of WHO. Bicarbonate and carbonate values, which impart alkalinity to water, range between 84.84-398.9 mg/l with average of 195.9 mg/l and 12.4-28.8 mg/l with an average of 20.14 mg/l respectively. The concentration of fluoride in the groundwater is although a cause of concern as almost 53% of the samples (8 out of 15) contain greater than 1.5 mg/l of fluoride with the highest value going up to 4.75 mg/l, almost thrice of the permissible level.

The various types of physiological damages that can be caused to the human body due to presence of the measured parameters in potable and drinking water beyond

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Parameter</th>
<th>Unit</th>
<th>WHO Standard</th>
<th>BIS Standard</th>
<th>% of Samples Beyond limit</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>pH</td>
<td>-</td>
<td>-</td>
<td>6.5-8.5</td>
<td>0</td>
<td>Bitter taste</td>
</tr>
<tr>
<td>2.</td>
<td>EC</td>
<td>µS/cm</td>
<td>500</td>
<td>500</td>
<td>13.33</td>
<td>Gastro-intestinal irritation</td>
</tr>
<tr>
<td>3.</td>
<td>TDS</td>
<td>mg/l</td>
<td>100</td>
<td>500</td>
<td>0</td>
<td>Scale formation</td>
</tr>
<tr>
<td>4.</td>
<td>Hardness</td>
<td>mg/l</td>
<td>75</td>
<td>75</td>
<td>0</td>
<td>Scale formation</td>
</tr>
<tr>
<td>5.</td>
<td>Calcium</td>
<td>mg/l</td>
<td>50</td>
<td>50</td>
<td>0</td>
<td>Encrustation in water supply pipelines</td>
</tr>
<tr>
<td>6.</td>
<td>Magnesium</td>
<td>mg/l</td>
<td>200</td>
<td>200</td>
<td>0</td>
<td>Scale formation</td>
</tr>
<tr>
<td>7.</td>
<td>Sodium</td>
<td>mg/l</td>
<td>200</td>
<td>200</td>
<td>0</td>
<td>Scale formation</td>
</tr>
<tr>
<td>8.</td>
<td>Potassium</td>
<td>mg/l</td>
<td>200</td>
<td>200</td>
<td>0</td>
<td>Interference with nervous impulses</td>
</tr>
<tr>
<td>9.</td>
<td>Iron</td>
<td>mg/l</td>
<td>0.1</td>
<td>0.3</td>
<td>66.67</td>
<td>Promotes bacterial growth</td>
</tr>
<tr>
<td>10.</td>
<td>Chloride</td>
<td>mg/l</td>
<td>200</td>
<td>250</td>
<td>0</td>
<td>Salty taste</td>
</tr>
<tr>
<td>11.</td>
<td>Carbonate</td>
<td>mg/l</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>12.</td>
<td>Bicarbonate</td>
<td>mg/l</td>
<td>300</td>
<td>600</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>13.</td>
<td>Sulphate</td>
<td>mg/l</td>
<td>250</td>
<td>200</td>
<td>0</td>
<td>Laxative effects</td>
</tr>
<tr>
<td>14.</td>
<td>Nitrate</td>
<td>mg/l</td>
<td>-</td>
<td>50</td>
<td>0</td>
<td>Methanoglobulinemia/Blue Baby Syndrome</td>
</tr>
<tr>
<td>15.</td>
<td>Fluoride</td>
<td>mg/l</td>
<td>1.5</td>
<td>1.5</td>
<td>53.33</td>
<td>Dental/Skeletal Fluorosis</td>
</tr>
</tbody>
</table>

Table 2. WHO/BIS Standards of Analysed Parameters with % of Samples falling within the Limits along with the Physiological and Industrial Effects

DOI: https://doi.org/10.30564/jees.v2i2.2479
the permissible limits and the wide range of damages that are also caused to the piped line distribution systems put in place for supply of stored groundwater have also been shown in Table 2. In the particular study area, people consuming groundwater are thus prone to enhanced bacterial growth and dental fluorosis as both iron and fluoride are present in elevated levels in the water samples analyzed.

### 4.2 Hydrogeochemical Evolution

For interpreting and understanding the role of the dominant cations and anions in groundwater several scatter plots have been put to use. Each scatter indicates how the ions involved affect and control the groundwater chemistry. The concentrations of all the ions have been measured in meq/l while plotting these graphs. Table 3 presents the correlation coefficient matrix, bearing the correlation coefficients generated through cross plotting of all the analyzed parameters.

The scatter plots 3a and 3b have been plotted using the Ca+Mg against TZ and Na+K against TZ respectively, where TZ is the total of the concentrations of major cations in groundwater. In both plots we can see that the samples fall near the (1:1) equiline. These trends suggest that all the four cations are dominant in the groundwater samples and alter the groundwater chemistry in their own capacity. Khoyrasole being an agriculturally dominant area the presence and prominent dominance of K and Na is well understood. On the other hand both Ca and Mg, which are sourced from carbonate minerals weathering also, exhibit their presence quite well.

In plots 3c and 3d, HCO$_3^-$ and HCO$_3^-$ + SO$_4^{2-}$ have been plotted against Ca+Mg respectively. In 3c, the samples fall majorly near the equiline indicating the source of these alkaline earth metals in water is majorly sourced from limestone dissolution. In case of plot 3d similar trends are shown which again reassures the fact that dissolution of Ca and Mg into groundwater is not majorly influenced by other minerals such as muscovite or calcite.

In the next series of scatter plots, both cations and anions have been plotted against each other to determine the dominant processes active in the system and sources of ions into groundwater. Plot 4a, where Na has been plotted against Cl$^-$, all the samples fall above the equiline and mostly towards Na axis indicating that salinization is not a dominant feature in the groundwater chemistry of this particular area, which has also been reflected in low values of chloride in the water samples assessed. Plot 4b, where Cl$^-$ + SO$_4^{2-}$ has been plotted against Na+K, majority of the samples fall below the equiline, towards the Na+K axis - indicating that primary salinity processes - such as rainfall and gradual dissolution of minerals are the major sources imparting salinity or alkalinity to the groundwater in the region. In case of plot 4c, where Ca has been plotted against SO$_4^{2-}$, we can observe that the samples are scattered almost all over the plot indicating that the source of calcium in groundwater is almost equally sourced from gypsum (a common source of calcium and sulphate) as

### Table 3. Correlation Coefficient Matrix (Presenting the Spearman Coefficients)

<table>
<thead>
<tr>
<th></th>
<th>pH</th>
<th>EC</th>
<th>TDS</th>
<th>Hardness</th>
<th>Ca</th>
<th>Mg</th>
<th>Na</th>
<th>K</th>
<th>Fe</th>
<th>Cl</th>
<th>CO$_3$</th>
<th>HCO$_3$</th>
<th>SO$_4$</th>
<th>NO$_3$</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EC</td>
<td>0.35</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TDS</td>
<td>0.25</td>
<td>0.04</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hardness</td>
<td>0.12</td>
<td>-0.01</td>
<td>0.94</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ca</td>
<td>0.28</td>
<td>0.01</td>
<td>0.94</td>
<td>0.90</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mg</td>
<td>-0.60</td>
<td>-0.04</td>
<td>-0.03</td>
<td>0.02</td>
<td>-0.09</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Na</td>
<td>0.32</td>
<td>0.23</td>
<td>0.81</td>
<td>0.79</td>
<td>-0.14</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>-0.26</td>
<td>0.34</td>
<td>-0.56</td>
<td>-0.43</td>
<td>-0.53</td>
<td>0.03</td>
<td>-0.11</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fe</td>
<td>-0.46</td>
<td>-0.11</td>
<td>-0.30</td>
<td>-0.16</td>
<td>-0.27</td>
<td>-0.14</td>
<td>-0.34</td>
<td>0.07</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cl</td>
<td>0.16</td>
<td>0.04</td>
<td>0.94</td>
<td>0.91</td>
<td>0.85</td>
<td>0.13</td>
<td>0.81</td>
<td>-0.47</td>
<td>-0.32</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO$_3$</td>
<td>0.26</td>
<td>-0.06</td>
<td>0.38</td>
<td>0.41</td>
<td>0.36</td>
<td>0.03</td>
<td>0.52</td>
<td>0.06</td>
<td>-0.62</td>
<td>0.36</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HCO$_3$</td>
<td>0.10</td>
<td>0.08</td>
<td>0.73</td>
<td>0.67</td>
<td>0.65</td>
<td>-0.15</td>
<td>0.47</td>
<td>-0.35</td>
<td>-0.12</td>
<td>0.62</td>
<td>0.32</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SO$_4$</td>
<td>0.38</td>
<td>0.13</td>
<td>0.41</td>
<td>0.55</td>
<td>0.55</td>
<td>-0.12</td>
<td>0.39</td>
<td>-0.08</td>
<td>-0.28</td>
<td>0.31</td>
<td>0.45</td>
<td>0.29</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO$_3$</td>
<td>0.07</td>
<td>0.36</td>
<td>-0.48</td>
<td>-0.49</td>
<td>-0.53</td>
<td>-0.17</td>
<td>-0.38</td>
<td>0.30</td>
<td>0.03</td>
<td>-0.41</td>
<td>-0.23</td>
<td>-0.19</td>
<td>-0.20</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>0.44</td>
<td>-0.26</td>
<td>-0.27</td>
<td>-0.39</td>
<td>-0.40</td>
<td>-0.40</td>
<td>-0.37</td>
<td>-0.25</td>
<td>-0.13</td>
<td>-0.24</td>
<td>-0.12</td>
<td>-0.29</td>
<td>-0.37</td>
<td>0.24</td>
<td>1.00</td>
</tr>
</tbody>
</table>
well as other minerals like limestone/calcite etc.

Plot 4d, presenting the scatter plot of TZ against HCO$_3^-$ indicates that the not geogenic and natural reasons are a dominant factor behind controlling the hydrogeochemical evolution of groundwater in the study area.

Plots 5a and 5b, where Ca+Mg and Na+K have been plotted against Cl$^-$ respectively, indicate that there is no sign of increased salinity due to secondary salinity procedures in groundwater of the particular study area chosen.
4.3 Groundwater Suitability for Irrigation

For evaluation of the groundwater quality with respect to irrigational suitability parameters like SAR (Sodium Adsorption Ratio), Permeability Index (PI), Magnesium Adsorption Ratio (MAR), %Na, Mg/Ca Ratio and the Chloro Alkaline Indices I/II have been calculated and compared.

If the water used in irrigation contains high sodium and low in calcium, the ion-exchange complex may become saturated with sodium which demolishes the structure of the soil, owing to the clay particles dispersion \(^{[28]}\) and the plant growth is reduced. Irrigation water with excessive salinity diminishes the osmotic activity of plants \(^{[29]}\). If the Sodium percentage is greater than 50%, it should be considered as a warning of sodium hazard. However, during the year 1954, it was decided that the term “sodium percentage” is to be changed and a new name the “Sodium Adsorption Ratio” or “SAR” came into existence as it is directly related with the adsorption of sodium by soils \(^{[30]}\).

The salts, not only affects the plant growth directly, it also affects soil structure, permeability and aeration, which affect plant growth indirectly \(^{[31]}\).

The permeability of soil is affected by long-term use of irrigation water and is influenced by sodium, calcium, magnesium and bicarbonate contents in soil. Another modified criterion has evolved based on the solubility of salts and the reaction occurring in the soil solution from cation exchange for estimating the quality of agricultural waters \(^{[32]}\). Soil permeability is affected by long-term use of irrigation water and is influenced by - (1) Total dissolved solids, (2) sodium contents and (3) bicarbonate content.

The indices of Chloro - alkalinity, (CAI I and CAI II), commonly known as indices of Base Exchange \(^{[33,34]}\) are considered as indicators to delineate as to whether ion exchange or reverse ion exchange has taken place in groundwater. If there is an exchange between Na and/or K in groundwater with Mg and/or Ca in the aquifer material, both of the indices are positive, indicating direct ion exchange. When the reverse of this process occurs, the indices have a negative value, indicating reverse ion exchange \(^{[35,36]}\). The equations used for the parameters explained above, have been presented in the block below, where concentrations of all ions are have been expressed in meq/l. Table 4 presents the range of each calculated parameter in water samples and Table 5 presents their categories, classifications and percentage of samples falling in each category.

### Table 4. Statistical Summary of the Calculated Parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Median</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAR</td>
<td>0.29</td>
<td>1.4</td>
<td>0.97</td>
<td>1.03</td>
<td>0.33</td>
</tr>
<tr>
<td>PI</td>
<td>13.81</td>
<td>76.64</td>
<td>49.63</td>
<td>50.62</td>
<td>14.24</td>
</tr>
<tr>
<td>MAR</td>
<td>19.73</td>
<td>90.55</td>
<td>50.21</td>
<td>47.3</td>
<td>18.14</td>
</tr>
<tr>
<td>Mg/Ca</td>
<td>0.25</td>
<td>9.58</td>
<td>1.68</td>
<td>0.9</td>
<td>2.35</td>
</tr>
<tr>
<td>%Na</td>
<td>5.68</td>
<td>36.2</td>
<td>23.66</td>
<td>24.19</td>
<td>7.66</td>
</tr>
<tr>
<td>CAI I</td>
<td>-5.94</td>
<td>0.46</td>
<td>-1.64</td>
<td>-1.06</td>
<td>2</td>
</tr>
<tr>
<td>CAI II</td>
<td>-0.61</td>
<td>0.42</td>
<td>-0.13</td>
<td>-0.16</td>
<td>0.26</td>
</tr>
</tbody>
</table>

\[
\text{SAR} = \frac{[\text{Na}]}{([\text{Ca}^2+] + [\text{Mg}^2+])}^{1/2}
\]

\[
\text{PI} = \text{Na}^+ + \left[ (\text{HCO}_3^- / (\text{Ca}^2+ + \text{Mg}^2+ + \text{Na}^+)) \right] \times 100
\]

\[
\text{MAR} = (\text{Mg}^2+ \times 100) / (\text{Ca}^2+ + \text{Mg}^2+)
\]

\[
\%\text{Na} = \frac{([\text{Na} + \text{K}])}{(\text{Ca} + \text{Mg} + \text{Na} + \text{K})} \times 100
\]

\[
\text{CAI} = \frac{[\text{Cl}^- - (\text{Na} + \text{K})]}{[\text{Cl}^-]}
\]

\[
\text{CAI} = \frac{[\text{Cl}^- - (\text{Na} + \text{K})]}{[\text{SO}_4^{2-} + \text{HCO}_3^- + \text{CO}_3^{2-} + \text{NO}_3^-]}
\]

### Table 5. Classification Levels of Calculated Parameters with % of Samples within Each Category

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Class</th>
<th>Description</th>
<th>% of Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAR</td>
<td>0 - 10</td>
<td>Low sodium hazard - suitable for all soils</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>10 - 18</td>
<td>Medium sodium hazard - suitable for coarse textured soils</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>18 - 26</td>
<td>High sodium hazard - generally harmful for most soil types</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>&gt; 26</td>
<td>Very high sodium hazard - unsuitable</td>
<td>0</td>
</tr>
<tr>
<td>PI</td>
<td>&lt;25</td>
<td>Class I</td>
<td>6.67</td>
</tr>
<tr>
<td></td>
<td>25-75</td>
<td>Class II</td>
<td>86.67</td>
</tr>
<tr>
<td></td>
<td>&gt;75</td>
<td>Class III</td>
<td>6.67</td>
</tr>
<tr>
<td>MAR</td>
<td>≤ 50</td>
<td>Suitable</td>
<td>66.67</td>
</tr>
<tr>
<td></td>
<td>&gt; 50</td>
<td>Unsuitable</td>
<td>33.33</td>
</tr>
<tr>
<td>%Na</td>
<td>&lt;20</td>
<td>Excellent</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>20 - 40</td>
<td>Good</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>40 - 60</td>
<td>Permissible</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>60 - 80</td>
<td>Permissible</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>&gt; 80</td>
<td>Unsuitable</td>
<td>0</td>
</tr>
<tr>
<td>CAI</td>
<td>Positive</td>
<td>Na &amp; K from water with Ca &amp; Mg in aquifer Matrix</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Negative</td>
<td>Ca &amp; Mg from water with Na &amp; K in aquifer Matrix</td>
<td>80</td>
</tr>
</tbody>
</table>
4.4 Hydrogeochemical Facies Evolution

For evaluation of the groundwater type and a lateral comparison of the major cations and anions present in the water samples two diagrams have been plotted - Piper Diagram (Figure 6) and the Schoeller Diagram (Figure 7). The Piper [37] plot allows comparisons between a large numbers of samples and it does not portray absolute ion concentrations. The main purpose of this plot is to show clustering of samples and thus determine the major water type prevalent in the study area. In the present study the water samples fall in the Ca-Mg-HCO$_3$ class of the Piper diagram, thus denoting that the water samples fall in the “fresh water” category.

![Figure 6. Piper Diagram](image1)

The Schoeller Diagram presents the concentration of the ions on a single plot using a logarithmic scale on the y-axis. This procedure enables to compare the concentration of each ion in spite of the vast disparity in quantitatively analysed values. The plot indicates that magnesium, sodium and potassium are mostly present in the samples in a similar range whereas the average concentration of calcium is higher than them. Among the anions, sulphate has the lowest values in comparison with chloride and carbonate. The Schoeller diagram pictorially presents that the parameter concentrations in almost all samples fall within the “desired limit or guideline” set by WHO and BIS.

5. Conclusions

From the various parameters analysed and the several factors calculated, it can be concluded that among the ionic concentration levels, two parameters iron and fluoride pose a major and immediate threat to the physiological well being of the residents of Khoyrasole who consume the groundwater directly. Besides these parameters, all other ionic concentrations fall within the permissible limits and pose no threat. Hydrogeochemical studies indicate that nor does any particular ion dominate the groundwater chemistry in this region solely, neither are any anthropogenic and secondary sources responsible for contamination of groundwater. In terms of irrigational suitability, majority of the water samples meet all criterions to be rendered suitable for the same. Only a handful of values indicate that a couple of samples have the potential to render low permeability to the soil in contact. Thus, sustainable management of water is possible in this study area if proper measures are taken to reduce the concentrations of iron and fluoride in groundwater. For both of parameters, domestic level treatment of precipitation and filtering can be adopted. Use of alum as a precipitant in case of iron and lime in case of fluoride can be adopted as immediate mitigation measures.

Conflict of Interest

We do hereby certify that there is no conflict of interest in this article.

References


[31] Singh, A.K., Mondal, G.C., Kumar, S., Singh, T.B.,


REVIEW
Achieving Sustainable Use and Management of Water Resources for Irrigation in Nigeria

Moses Oghenenyoreme Eyankware¹² Ezekiel Obinna Igwe¹ Christopher Ogwah¹ Ruth Oghenerukevwe Eyankware Ulakpa³

¹. Department of Geology, Ebonyi State University, Abakaliki Ebonyi State Nigeria
². Geo-Moses Consultancy Limited. Warri, Delta State, Nigeria
³. Department of Environment Management and Pollution Control, Nigeria Maritime University, Okkerenkoko, Delta State, Nigeria

ARTICLE INFO

Article history
Received: 27 October 2020
Accepted: 16 November 2020
Published Online: 30 December 2020

Keywords:
Geogenic
Anthropogenic
Irrigation indices
Suitability and Nigeria

ABSTRACT

Water resource is available in Nigeria to meet water demand for domestic, agricultural and industrial use. If well enhanced and protected from various source of pollution. However, less information is available on suitability of water resources for irrigation use in Nigeria. This article reviews literature of the past with regards to influence of geogenic and anthropogenic activities on water resource for irrigation purpose in Nigeria and also to explain the current state of suitability of water resource for irrigation studies in Nigeria and gaps in studies. It also summarizes future ways on water resource management and preventive measure for water resource pollution for irrigation use. Related articles were downloaded from Google scholar in water-related issues. This paper tends to review previous article on water resource in Nigeria, and its suitability for irrigation. The primary aim of this paper is to produce a synoptic overview of the water resources in Nigeria and its suitability for irrigation use. From paper reviewed it was observed that 89 % of water resources was considered suitable for irrigation.

1. Introduction

Recent studies have shown that scientific approach such statistical based approach, hydrochemical and other approach has been used for water resources quality assessment. With these approach, large geological, hydrological and biological data are simplified, organized and classified to produce useful information on water quality for various use ranging from domestic, industrial, irrigation and other use[1-5]. As the quality of water resource is most time influenced by geogenic and anthropogenic activities. The hydrogeochemical characteristics of groundwater is governed and influenced by groundwater quality and the rock/mineral-water interactions in the sub-surface aquifers and sometimes by inter mixing of two different aquifers[6]. Johnson, et al. [7] pointed out that the most widespread forms of geogenic contamination with effect on man and crops are elevated concentrations

*Corresponding Author:
Moses Oghenenyoreme Eyankware,
1. Department of Geology, Ebonyi State University Abakaliki Ebonyi State, Nigeria
2. Geo-Moses Consultancy Limited. Warri, Delta State, Nigeria
Email: geomoses203@gmail.com
of arsenic and fluoride. Geogenic contamination may also trigger concentrations of uranium \[^{[8,9]}\]
chloride \[^{[10]}\]
or sulfate \[^{[11]}\]. Grützmacher, et al. \[^{[12]}\]
stated that geogenic contamination is defined as the overstepping of certain thresholds (drinking water guidelines) in the groundwater without direct or indirect human influence. Often it is the result of long residence times combined with favorable geologic conditions and mineralogy of the groundwater. Several studies carried out has shown that hat anthropogenic activities resulting in its urbanization, mining, industrialization, landfill/dumpsite, pesticides washed off the land by rain, leachates, heavy metals, bacteriological pollution, overexploitation, poor recharge and chemical contamination are major concerns for groundwater sustainability \[^{[13-16]}\]. While in coastal area of Nigeria and other part of the world salinization has become a threat to groundwater quality. Numerous publication have reported salinization and potential sources of groundwater salinity in coastal groundwater, these include evaporite mineral dissolution \[^{[17-19]}\]
downward/upward saline groundwater seepage \[^{[20-22]}\]
brine migration \[^{[23,24]}\]
and mixing caused by poorly constructed wells \[^{[25]}\]
as well as seawater intrusion \[^{[26]}\]. Studies by Ocheri, et al. \[^{[27]}\]
stated that groundwater quality in cities areas are mostly controlled by the geogenic and geochemistry of the environment, rate of urbanization, landfill/dumpsite leachates, industrialization, bacteriological pollution, heavy metals, and effect of seasons. In the vein, surface water contamination is linked to increase in population, urbanization and industrialization. The potability of water resources for irrigation is evaluated by its mineralogy makeup, the type of the plant and the soil to be irrigated \[^{[28]}\]. The objectives of this study are to review potability of water resources in Nigeria for irrigation based on two category:

(1) Anthropogenic; these include; mining activities, unlawful waste disposal, leakage of septic tanks and application of pesticides.

(2) Geogenic factor; these include weathering and rock water interaction.

1.1 Climate and Vegetation

The study area is grouped into five vegetation zones namely; the coastal zone, tropical rainforest, Guinea Savannah, Sudan Savannah and Sahel \[^{[29]}\]. The climatic zones are shown in Figure 1 and grouped following the agro-climatic zones distribution (based mainly on rainfall and temperature) of the country, see Ayanlade, et al. \[^{[30]}\]
for more information as regards this.

1.2 Geology Setting

Geology of the Nigeria is divided into; Basement Complex, Younger granites, and Sedimentary Basins (Figure 2) for more on this see Obaje \[^{[31]}\].

Figure 1. Map showing Climatic zones in Nigeria; adapted from Akinsanola and Ogunjobi \[^{[29]}\]

Figure 2. Map of Nigeria showing three major geological component Basement, Younger Granites, and Sedimentary Basins

Source: Nuhu \[^{[32]}\].

2. Methods

Articles published within the last 5-10 years were reviewed to evaluate the influence of anthropgenic and geogenic activities on water resources quality and its suitability for irrigation use in Nigeria and also abate measure to reduce...
water resource pollution. Omlin, et al. [33] methods was adopted for this study. Article related to this study were searched by google search engines, open access journal sites (SCOPUS, Pub-Med, Taylor Francis, Elsevier and Springer etc.). These relevant articles and papers were read in full information gotten were stored in database with details of publication particulars, study location, period, approach, methodology for assessing influence of anthropogenic and geogenic activities, results of these activities, and major conclusion. Furthermore, to interpret the status and quality of work carried out in Nigeria, Omlin, et al. [33] method was employed for this study with some modifications to suit the aim and objectives of this paper. The steps that was adopted to evaluate the quality of the articles included the following;

(1) Geological terrain of were each of the paper belongs to (Basement complex, sedimentary basin and Niger Delta Basin)

(2) Detail description of subjective exposure of water resources was discussed (precipitation, water rock interaction, mining activities.

3. Result and Discussion

Factor that alter water resources quality for irrigation use in Nigeria (with emphasis on geogenic and anthropogenic activities).

(1) Geogenic (rock water interaction, weathering, etc.)

(2) Anthropogenic activities (marine pollution, sewage disposal, leakage of septic tanks and mining).

3.1 Related Article on Geogenic Factors

Aderibigbe, et al. [34] studied the potability of water resources for irrigation. Irrigation indices that they calculated for was Na %, from their study it was observed that water resources were within the excellent to permissible class, there study further revealed that the ions present in these water bodies are dominantly controlled by chemical weathering and none was assigned to precipitation processes. Eyankware. [35] evaluated the groundwater quality at Ekaeru Inyimagu for irrigation using hydrochemical approach and irrigation indices findings from the study revealed that groundwater within the area of study was considered suitable for irrigation. Further results, from the findings revealed that the dominant species in groundwater is $\text{Cl}^-$, result from Gibbs plot, further showed that rock water interaction is the major process that influencing groundwater chemistry. Estimated result from irrigation indices showed that soluble sodium percentage (SSP), magnesium absorption ratio (MAR), Permeability index (PI), residual sodium bicarbonate (RSBC) and Kelly ratio (KR) fell within excellent to very good range, hence one could say groundwater for the study is considered suitable for irrigation. Ayuba, et al. [36] evaluated different rural communities wells, this positive correlation is an indication that the ions are controlled by the same geochemical factors. [35] further stated that based on (sodium percentage) Na % only one sample location has Na % less than 20% and it is classified excellent water type. Irrigation parameters calculated for were sodium percentage (Na %), SAR, magnesium hardness (MAR), PI and RSC. The RSC, MH, estimated from groundwater sample revealed that the values were parameters were below the guideline of 60 % and thus, are considered to be safe and fit for irrigation purposes. Eyankware, et al. [37] studied the suitability of water resources for irrigation in abandoned Nkalagu limestone mine pits, Ebonyi state Southeastern Nigeria. Indices calculated for were SSP, MAR, KR, Na %, SAR and TH. They stated that most of calculated parameters were considered suitable for irrigation, few sampling were considered unfit for irrigation and that high concentrations of the magnesium and calcium showed that the area is of carbonate terrain and there is evidence of water rock interaction. Oladeji, et al. [38] evaluated the quality of groundwater for irrigation at Otte village, Kwara state Nigeria within two geologic formation Migmatitic and Granitic gnnesis. They concluded that the water samples obtained from areas underlain by the Migmatitic gneiss tends to be relatively suitable for irrigation, when compared to those underlain by the Granitic gneiss. Talabi, et al. [39] studied surface water and shallow water bearing formation in Ekiti state, the area falls within the Basement Complex, there study was subjected to seasonal variation. Findings from there revealed that 90 % of TH from surface water showed is less than 70 mg/L this implies that surface water is considered soft, with low effect of mineralized water and no pronounced effect of water interaction from transient to residence time. They further pointed out that irrigation indices such as; SAR, RSBC and PI showed signified good quality water suitable for irrigation, while MAR and Kelly’s ratio were indicative of moderately suitable irrigation water. Aleke and Nwachukwu [40] studied the suitability of basement aquifer at Abuja, Nigeria, for irrigation. They were of the opinion that geochemical facies of the groundwater is of Ca-$\text{Cl}^-$ water type, this implies that over a long period of time, water-rock interaction has altered groundwater chemistry. [41] Their findings revealed that the major processes influencing groundwater are weathering, mineral dissolution and ion exchange. Irrigation indices such as SAR, KR, TH, PI, and RSC showed that the groundwater within the study area is suitable for irrigation, except MR which showed that groundwater is fairly unsuitable for
irrigation. According to Talabi [41] stated that groundwater is suitable for irrigation, and further stated that rock water interaction influence its chemistry as it reflect on it physicochemical composition, water facies and irrigation quality. Hence groundwater within selected part of Ikere, Ekiti is considered fit for irrigation. Omo-Irabor, et al. [42] stated that pH shows that groundwater falls within slightly acidic to basic, and are within acceptable range for irrigation purpose. They evaluated groundwater at Ibinta with emphasis on its suitability for irrigation, from hydrogeochemical facies plot, the dominant water type from piper plot is SO42− + Mg2+ type, from Scholler diagram groundwater trend in Mg2+>SO42−>Cl−>HCO3−>Na+>Ca2+ and the Wilcox diagram showed that the groundwater ranges between permissible to excellent class, Gibbs plot revealed that rock water interaction is the major process that influence groundwater. Result from irrigation parameters revealed that SSP, Na%, KR and TH were below the permissible limit for irrigation, based on these ground water is considered fit for irrigation. Talabi, et al. [39] assessed the suitability of surface water for irrigation using indices such as SAR, RSC, PI and KR results from their study showed that surface water fell within excellent to good. [31], Gibbs plot depicted that the geochemistry of water were influenced by chemical weathering controlled by precipitation as the major factor controlling the chemistry of the surface waters. According to Nwankwoala, et al. [43] higher percentage of groundwater model in selected part of Otuko and environs, Bayelsa State were considered suitable for irrigation purpose except for KR, its suitability status were assessed using irrigation models such as; SAR, PS, PI, Na %, KR, and MAR. Onyeabor and Nwatrali [44] assessed surface water around Enyigba mine for irrigation, model use for the evaluation was SAR, from their findings they stated that the water is fit for irrigation. Egirani and Nomji [45] assessed groundwater in Markurdi, Benue state capital. A total of eight groundwater sample were analyzed from there finding it was observed that water is considered suitable for irrigation. In the same vein Ekpe, et al. [46] assessed surface and groundwater in selected water resource in southeastern Nigeria. Their findings revealed that water resources were considered suitable for irrigation. Eyankware, et al. [47] evaluated groundwater of Oju, Benue State with emphasis on its suitability for irrigation, indices used to assess the suitability of sampled water were Ec, MAR, SAR, TH, Na %, SSP, Gibbs plot and plot of SAR against Ec. Their findings showed that over 94% of sampled point where considered suitable for irrigation, although high TH value was observed at some and hence such points were considered unsuitable for irrigation.

3.2 Related Article on Anthropogenic Activities

Eyankware, et al. [48] conducted an assessment of influence of mining of water quality for irrigation at Mkpuma Ekwaoku mining district. Parameters analyzed for were; TH, SAR, MAR, KR, Na % and SSP. From there findings, it was observed that TH and Na% at some sampling points were slightly above the set standard, that implies mining might have affected the suitability of water for irrigation at those points that are above the set standard. Ethan, et al. [49] evaluated of water quality for irrigation at Badeggi and Edozigidi, indices calculated for were SAR and Na %. They stated that the quality of water resources for irrigation falls within moderate category according to FAO Standard [50]. Omotoso and Ojo [51] studied the quality of river Niger floodplain water at Jebba central for irrigation. Indices calculated for were SAR, MAR, RSC, permeability index (PI), Potential salinity (PS) and SSP. From there findings, the water is of suitable for irrigation. Except for magnesium absorption ratio and Kelly ratio at some locations where considered unfit for irrigation, [43], stated that surface water (River Niger, Oshin and Ndafa) were used for Josepdam irrigation scheme. From their findings water show no salinity tendency from SAR value, while pH is within the recommended FAO standard [50]. Eyankware, et al. [52] evaluated groundwater quality for irrigation at Warri, Niger Delta Region. Irrigation parameters calculated for were; SSP, MAR, SAR, PI and PS. They observed that SSP, MAR, SAR, PI, EC, Potential salinity (PS) were below the set standard and considered fit for irrigation purpose. Except for TH and KR that were above the set standard at some sampling points, concluded that groundwater is considered fairly good for irrigation. Eyankware, et al. [53] studied the suitability of groundwater for irrigation at Eruehumokwarien Community, Niger Delta Region. Indices calculated for were: SAR, KR, MAR, PI, Na % and SSP, their results showed that groundwater was considered suitable for irrigation. Eyankware [54] evaluated the impact of mining on groundwater within the Umuohara mining district in Ebonyi State, southeastern Nigeria. Geologically, the area lies within the Asu River Group of Southern Benue Trough. Irrigation parameters such as PI values were below the set standard for irrigation. Values of KR, RSBC, SSP, Na%, TH and Ec were above the set standard at some sampling points. Tsuzom, et al. [55] studied surface water quality at Kaduna from their findings it was observed Ec and potassium concentration in sampled water were above the irrigation guideline values across the sampling points; boron concentrations were close to guideline value at two sampled point, estimated values from SAR exceeded the guideline value at four of the six sampling.
Table 1. Related references on water resource studies for irrigation quality in Nigeria

<table>
<thead>
<tr>
<th>Author (s)</th>
<th>Location</th>
<th>Geology</th>
<th>Data Source</th>
<th>Field of Study</th>
<th>Sampling Number</th>
<th>Year of Publication</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>Egirani, and Nonji</td>
<td>Benue</td>
<td>Sedimentary terrain</td>
<td>Journal article</td>
<td>Water analysis</td>
<td>8</td>
<td>2002</td>
<td>Preliminary investigation of the hydro-geochemical characteristics of groundwater in parts of the Makurdi formation, Nigeria</td>
</tr>
<tr>
<td>Omotoso and Ojo</td>
<td>Jebba</td>
<td>Journal article</td>
<td>Water analysis</td>
<td>2012</td>
<td></td>
<td></td>
<td>Assessment of quality of river Niger floodplain water at Jebba, central Nigeria: implications for irrigation</td>
</tr>
<tr>
<td>Ethan and Yunsua</td>
<td>Niger</td>
<td>Journal article</td>
<td>Water analysis</td>
<td>2014</td>
<td></td>
<td></td>
<td>Assessment of the Quality of Irrigation Water at the Badeggi and Edozighi Irrigation Schemes</td>
</tr>
<tr>
<td>Ekpe</td>
<td>Ebonyi</td>
<td>Sedimentary terrain</td>
<td>Journal article</td>
<td>Water analysis</td>
<td>2014</td>
<td></td>
<td>Miscellaneous Properties of Irrigation Water Sources of Ebonyi State Southeast Nigeria</td>
</tr>
<tr>
<td>Eyankware</td>
<td>Ebonyi</td>
<td>Sedimentary terrain</td>
<td>Journal article</td>
<td>Water analysis</td>
<td>6</td>
<td>2016a</td>
<td>Hydrochemical Appraisal of Groundwater for Irrigation Purpose; a case study of Ekaeru Inyimagu and its adjoining area, Ebonyi State, Nigeria</td>
</tr>
</tbody>
</table>

DOI: https://doi.org/10.30564/jees.v2i2.2505
points. Their findings showed the need for the Nasarawa stream water to be subjected to some level of treatment especially during the dry season when the level of dilution by rain water will be absent and then water will be considered suitable for irrigation. Tsuzom and Olaniya [55] studied the suitability of Nasarawa stream for irrigation in Kaduna south local government. Irrigation indices applied for this study were SAR, RSC and Ec. Results from their studies revealed that indices studied were below the set standard. Hence sampled water is considered suitable for irrigation.

3.3 Usage of Water Resource for Irrigation

Findings from the literature analysis revealed that groundwater is more evaluated for irrigation purposes than surface water. Surface water is believed to be more prone to pollution when compared to surface due to the fact it exposed to all kind of pollutant i.e landfill, septic tanks and oil spill. Although groundwater is not easily polluted when compared to surface water, but it could be difficult to remediate contaminants once pollution occurs [57,58]. It was observed that groundwater was evaluated more for groundwater with percentage of 79.6% when compared to surface water with 20.4% as shown in Figure 4.

3.4 Type of Pollutant that Alter Water Quality for Irrigation in Nigeria

Various kind of pollutant are responsible for water quality alteration for irrigation in Nigeria, such factors could be domestic waste, acid-rain that occur in oil and gas producing region of Niger Delta Region of Nigeria. [59] suggested that sources of surface water pollution in Nigeria are solid mineral exploration, oil and gas, industrial effluent, hydrogeology, domestic waste and sewage, and agriculture. They further stated that groundwater pollution in Nigeria are landfill leachate, hydrogeology, industrial effluent, urbanization, poor well construction, domestic waste and sewage and, oil and gas.
4. Conclusion

From detailed study, it was observed that unsuitability of water resources for irrigation use could be attributed to anthropogenic activities and geogenic activities. From reviewed literature, it was observed that 59% of within water resources the sedimentary terrain is influenced by rock-water interaction, 41% is influenced by anthropogenic activities. While, within the hard rock terrain 67% of water resources is influenced by geogenic activities, 33% is influenced by anthropogenic activities. Irrigation indices such as SAR, TH, SSP, Na %, MAR, CAI, RSBC, KR, PI Gibbs plots and PI, showed that 71% of water resource in Nigeria was considered suitable for irrigation, 29% is considered slightly unsuitable for irrigation, various authors revealed that the unsuitability of water resources for irrigation, could be linked to mineralogy constituents of water bearing units for both hard rock and sedimentary terrain. Irrigation parameters analyzed by various authors revealed that 90% of analyzed water falls within excellent and good category. Various authors were of the opinion, that although groundwater chemistry was influenced by weathering processes it’s has little or no influence on suitability of water resources for irrigation.

Recommendations

In addressing these aforementioned challenges, the following recommendation should be taken into consideration:

(1) Relevant law enforcement agencies should try and enforce strict adherent to disposal of waste close to surface water bodies to avoid decline in surface water quality.

(2) Relevant authorities should ensure that water quality criteria should be used as a guideline to define proper management practices in irrigated agriculture.

(3) Water resources should be monitored from time to time by relevant agencies to avoid total deterioration of water quality for irrigation.

References


[18] Sajil Kumar, P.J. Deciphering the groundwater-saline water interaction in a complex coastal aquifer in South India using statistical and hydrochemical mixing models. Earth Syst. Environ, 2016, 2: 194


[38] Oladeji, O. S. Adewoye, A.O. Adegbola, A. A..


DOI: 10.19080/IJESNR.2018.16.555926


DOI: https://doi.org/10.1016/j.resconrec.2019.104463

REVIEW
Methane and Hydrogen Storage in Metal Organic Frameworks: A Mini Review

Oghenegare Emmanuel Eyankware1* Idaeresoari Harriet Ateke2
1. TegaFej Consulting Services, Port Harcourt, Rivers State, Nigeria
2. Department of Petroleum and Gas Engineering, University of Port Harcourt, Rivers state, Nigeria

ARTICLE INFO
Article history
Received: 30 November 2020
Accepted: 9 December 2020
Published Online: 30 December 2020

Keywords:
Methane
Hydrogen
Metal organic framework
Adsorption
Storage
Computational

ABSTRACT
The need for a net zero carbon emission future is imperative for environmental sustainability hence, intensive carbon fuels would need to be replaced with less carbon emitting energy sources such as natural gas till clean energy source such as hydrogen becomes commercialized. As a result, this mini review discusses the use of metal organic framework (MOF) for adsorption of methane and hydrogen in specially designed tanks for improved performance so as to increase their applicability. Herein, adsorption (delivery) capacity of selected high performing MOFs for methane and hydrogen storage were highlighted in reference to the targets set by United States Department of Energy’s Advanced Research Projects Agency-Energy (ARPA-E) and Fuel Cells Technology Office. In this regard, specific design and chemistry of MOFs for improved methane and hydrogen adsorption were highlighted accordingly. In addition, an overview of computational and molecular studies of hypothetical MOFs was done - the various approaches used and their proficiency for construction of specific of crystalline structures and topologies were herewith discussed.

1. Introduction

The continuous global emission of greenhouse gases (GHGs) particularly carbon (IV) oxide (CO₂ hereafter) into the atmosphere from utilization of fossil fuels (coal and crude oil) for energy production has been identified as the leading cause of global warming and climate change[1]. This is further exacerbated by the increasing atmospheric CO₂ concentration from 280 ppm at pre-industrial revolution era[2] to 411.28 ppm in October, 2020[3] as shown in Figure 1 due to increasingly number of the world’s developing economies that use readily available and cheap energy sources such as coal and crude oil for energy generation to drive their respective economic activities. This challenge posed to environmental sustainability in the form of extreme weather events such as drought, increasing sea levels and deforestation etc. that threaten human development and existence therefore necessitates the need to investigate and deploy less carbon emitting carbon energy sources such as natural gas or better still deploy clean energy sources such as hydrogen that would have limit CO₂ emissions and facilitate achievement of net zero carbon future via cleaner energy sources - natural gas combustion emits 49% and 25% less CO₂ than coal (anthracite) and crude oil (gasoline) respectively (unit of measurement is pound CO₂ per million Btu of...
energy produced) while combustion of hydrogen does not produce CO$_2$ as a by-product (cleanest energy source).

In order to use these less carbon emitting fuels for practical and industrial applications, they have to be stored in carriage systems, preferably high pressure storage vessels; this becomes even more important as these energy sources exist in gaseous phase at atmospheric conditions (low pressures and ambient temperatures) with high entropy and system disorderliness; unfortunately, herein lays the drawbacks of using these energy sources for commercial applications. The difficulty in storing these gases and the limited amount that can be stored in carriage systems for a certain period of time limits their applicability. For example, it is reported that 5 - 13 kg of hydrogen needs to be stored for an automobile to drive a distance of 300 miles[^8]; same applies to natural gas storage in carriage systems which conclusively highlights that carriage systems need to be refilled often, limiting their applicability. In addition, high pressure gas storage systems that are costly would be needed to store these gases on vehicles and process systems for commercial and industrial applications.

Therefore, prevailing technologies for storing these gases operate at high pressures - methane is currently being stored at high pressures of 250 bar [for compressed natural gas (CNG), will be discussed in later section] while hydrogen is stored at high pressures of 700 bar, highlighting the need to design special storage tanks, high cost of storage[^10] and possible safety concerns that arise due to these factors highlighted. Considering these prevailing drawbacks, there is need to design advanced technologies such as compressed natural gas (CNG), liquefied natural gas (LNG), natural gas hydrates (NGH) and adsorbed natural gas (ANG) for NG storage and compressed gaseous storage, liquid storage and solid-state storage for hydrogen storage that would store gases at low pressures at ambient conditions while exhibiting high storage capacity that is critical to increase the propensity of deploying natural gas and hydrogen for commercial and industrial applications.

This has necessitated intense research into these highlighted advanced technologies and storage mechanism that can store these gases at low pressures and ambient temperatures where applicable. As a result, this review seeks to evaluate the most promising of these advanced storage technologies for methane and hydrogen storage with focus on ANG due to its promising properties. Herein, an advanced and porous adsorbent, metal organic framework was would be discussed with focus on highlighting its outstanding properties for methane storage would be discussed in view of highlighting advances that have been recorded in recent years.
2. Methane and Hydrogen Storage

In this section, different existing technologies and storage mechanisms used for methane and hydrogen storage would be highlighted. Particular attention would be paid to their characteristics that make them suitable or not suitable for commercial and industrial applications. Finally, the most suitable of these technologies would be highlighted for further discussion.

2.1 Mechanisms for Methane Storage

Currently, there are established and popular technologies for storage of methane - these include LNG and CNG. Also, there are other mechanisms of methane storage such as NGH and ANG that are active areas which seeks to ameliorate the drawbacks of the popular storage technologies for process and energy methane storage. These different mechanisms will be discussed as follows;

Different methods have been proposed and used for natural gas storage. Chen et al. itemized them as;

(1) Liquefied Natural Gas (LNG)
(2) Compressed Natural Gas (CNG)
(3) Natural Gas Hydrates (NGH)
(4) Adsorbed Natural Gas (ANG)

2.1.1 Liquefied Natural Gas (LNG)

LNG is a form of natural gas that exists at cryogenic conditions of -161°C and ~ 1 bar - it is 600 times denser than natural gas in its gaseous phase hence; it outperforms natural gas in terms of efficiency of storage and transportation across long distances in the absence of pipeline networks. Also, its volumetric energy density is higher than CNG at 22.2 MJ/L (-161°C and 0.9 bar) as against 9.06 MJ/L (250 bar). Due to its efficacy for long distance transportation, different processes and cascades that facilitate an LNG value chain have been developed and patented for natural gas liquefaction; a popular liquefaction process known as mixed propane refrigerant liquefaction process is shown in Figure 2. As highlighted in the liquefaction process below, a typical process involves basic processes such as pre-treatment of natural gas, acid gas removal, dehydration, removal of impurities such as mercury and other trace elements and liquefaction process using different process loops with cryogenics for purposes of heat exchange.

Figure 2. C3-MR liquefaction process, reproduced from[11]

Despite the suitability of LNG for long distance transportation of methane, the cryogenic conditions at which it must be stored necessitating the use of special membrane tanks limits its usage in conventional process systems. In addition, the high cost of installation of baseload LNG liquefaction plants in correspondence to their energy intensive processes results to high cost of operations[12] which consequently hinders the rapid commercial and industrial applicability of LNG. Hence, it becomes difficult to use LNG in high carbon emitting sectors such as transportation and other conventional process systems obtainable in petrochemical industries.

2.1.2 Compressed Natural Gas (CNG)

Currently being used as an energy source in vehicles (deployed in Benin City, Nigeria), CNG has shown promising properties such as eco-friendliness, low cost of storage as compared to LNG, wide range of applicability and compatibility for spark and compression ignition engines[13] to prompt its commercial deployment. Its suitability as a means of storing methane is evident in the fact its volume is <1% of the volume of methane at standard atmospheric conditions due to its high pressure storage conditions (typical conditions of storing CNG ranges from 200 - 248 bar). Due to the merits of CNG for commercial usage, well developed processes have been patented for CNG production; one of such processes is shown in Figure 3.

Figure 3. Process Diagram of a typical CNG plant, reproduced from[14]; FGU - Flue Gas Unit, GSU - Gas Sweetening Unit, DHU - Dehydration Unit, HRU - Heavies Removal Unit, HSU - Heavies Separation Unit, LQU; Liquefaction Unit; NRU - Nitrogen Rejection Unit
Commercial application of CNG in process systems is faced with the challenge of storage at high pressures via multi stage compression cycles which requires designs of high pressure storage cylinders that are expensive and costly. Also, there are safety concerns especially when CNG is used on board vehicles. In all, CNG is faced with drawbacks which limit its applicability at commercial and industrial levels. In addition, CNG possesses low energy density of 8.8 MJ/L at 200 bar and 20°C which is 75% less than the energy density of gasoline\[^{15}\] that it seeks to displace in vehicular applications.

2.1.3 Natural Gas Hydrates (NGH)

Natural Gas Hydrates (NGH) are ice-like compounds made up of lattice of water with potential positions for guest molecules (in this case methane) at which temperatures and pressures at normal conditions occur in gaseous phase; in NGH, guest molecules possess ability to fit into the interstices of the water-ice lattice\[^{16}\]. Amongst the different types of gas hydrates structures as structure I (sI), structure II (sII), and structure H (sH) that exist based on the cage structure of the lattice, NGH are regarded as sI as the methane easily fits into the lattice structure. Hence, NGH can be considered to be stable at high pressures and low temperatures therefore they are prevalent in deepwater of water bodies such as oceans. Also, NGH are high energy density compounds which highlights the high hydrocarbon content obtainable from these clathrates. It is reported that if 1 m\(^3\) of NGH is dissociation, it would release about 160 m\(^3\) of natural gas\[^{17}\] - the high reserve content of these deposits has facilitated in depth research into commercializing these huge reserves as a sources of primary energy. A typical lattice structure of NGH is shown in Figure 4.

![Figure 4. Diagrammatic representation of sI NGH: H - hydrogen atom, O - oxygen atom, C - carbon atom, filled and unfilled double lines - chemical bonds, reproduced by\[^{18}\]](https://doi.org/10.30564/jees.v2i2.2642)

Although NGH have been identified to be an abundant natural energy source (amount of NGH present in Arctic permafrost and under the oceans collectively represent about 53% of all fossil fuels present on earth\[^{16}\]), issues of exploration of this energy resource remains a challenge even though pilot tests for exploration has been carried out in Japan and China. Lack of well developed technology and the high cost of depleting it undermine its commercial and industrial applicability.

2.1.4 Adsorbed Natural Gas (ANG)

This mechanism of natural gas storage entails packing adsorbents in storage vessels in order to increase their storage capacities for installation onboard vehicles a shown in Figure 5. ANG possess characteristics such as high energy density and environmental friendliness which makes them capable to displace LNG, CNG and NGH for applicability. For instance, it is reported that use of ANG in vehicles emits less CO, NOx and hydrocarbon in the order of 99%, 30% and 96% respectively\[^{19}\]. In addition, storage of natural gas in non-cylindrical tanks at pressures of 35 - 40 bar affords flexibility in designing placement and configuration of the tank while ameliorating cost of compressing or liquefying natural gas for transportation and storage. Hence, ANG shows potential to be applied in the near future in systems such as gas holders used in peaking shaving LNG plants, drying chambers that are gas fired, solid sorption heat pumps that are also gas fired.

![Figure 5. Application of ANG in vehicles, reproduced from\[^{15}\]](https://doi.org/10.30564/jees.v2i2.2642)

The use of adsorbents for storage of adsorbates (in this case methane) is an active area of research. Using adsorption, an process wherein adsorbents adhere adsorbates to their solid surfaces at low pressures and ambient temperatures where applicable via van der Waals or chemical bonds as the case maybe\[^{20}\], as shown in Figure 5 presents a process and energy efficient option for storage of natural gas. This is due to the fact that adsorbents used for gas storage possess characteristics such as high adsorption capacity, low pressure and ambient storage of gases, thermal, chemical and mechanical stability, regenerability and low of production that make them suitable for commercialization. For instance, it is reported that the isosteric heat of adsorption ranges from 10 - 100 KJ/mol depending
on the type of adsorption (physical or chemical adsorption)\textsuperscript{[20]}, highlighting the low energy needed to regenerate the adsorbents and low cost of operation. In this regard, different adsorbents such as activated carbon\textsuperscript{[21]}, polymers\textsuperscript{[22]} and metal organic framework (MOF)\textsuperscript{[7]} have been studied for adsorption of methane in literature. Amongst these adsorbents, MOF have been have been revealed to show exceptional properties for methane storage due to its high methane adsorption capacity (arguably regarded as the high methane storage adsorbent) due to very high surface area, selectivity and controlled pore sizes\textsuperscript{[23]}. Hence, MOF would be the adsorbent of interest that would be reviewed for methane storage in this review.

**Figure 6.** Schematic of adsorption process for gas phases

Considering the different storage mechanisms for methane discussed hitherto, ANG has stood out as the only option that can be applied at conditions close to atmospheric conditions (low pressures and temperatures close to ambient conditions) in less expensive systems of storage and transportation making ANG more attractive for commercialization. However, for LNG, process conditions are cryogenic (temp. of -161°C and 100 bar); CNG is stored at very high pressures of 200-300bar as a supercritical fluid at room temperature and NGH involves difficult-to-attain conditions for its formation and slow formation rate. Consequently, challenges faced by LNG, CNG and NGH have therefore propelled ANG as the viable storage medium for NG.

### 2.2 Mechanism of Hydrogen Storage

Production of fuel cell vehicles by companies such as Hyundai, Roewe, Riversimple, Toyota and Honda that use hydrogen stored at high pressures of ~ 700bar as source of energy is gradually standard in the automobile industry. In addition, other mechanisms of storing hydrogen in process systems (particularly on board vehicles) have been investigated all in a bid to discover the most process and energy efficient storage mechanism for hydrogen and US Department of Energy (DOE) target for on board hydrogen highlighted in Table 1; this is due to the fact that storage mechanism currently being investigated cannot compete with gasoline at low pressures and temperatures. These several storage mechanisms are highlighted below; also, they would be discussed in detail in this section.

1. **Compressed Gaseous storage of hydrogen**

2. **Liquid storage of Hydrogen**

3. **Solid-state storage of Hydrogen**

#### 2.2.1 Compressed Gaseous Storage of Hydrogen

Compressed storage of hydrogen entails physical storage of hydrogen gas at high pressures of 350 - 750 bar that produces energy content of 4.4 MJ/L - value less than that obtainable in gasoline (31.6 MJ/L). Due to some attractive properties of compressed gaseous storage of hydrogen such as low energy for storage, low cost of operation (not as high other types of CNG storage), high speed of release of hydrogen gas at room temperatures and ability to maintain full service even at very low temperatures make this option of hydrogen to be most deployed. In this regard, three applications of hydrogen exist; they are bulk cargo transportation, stationary type and vehicle mounted application. However, use of hydrogen in vehicles is the most deployed\textsuperscript{[24]}; this vehicles, the cylinders used to store hydrogen are made of fiber filament winding composites lined with an inner metal bladder. One of such developed storage tanks is the typical vehicle mounted type IV compressed gaseous hydrogen vessel shown in Figure 7. A tank such as this has the capacity to store hydrogen at pressures of 350 - 700bar hence it can attain gravimetric storage capacity of 5 wt%.

**Figure 7.** Type IV typical vehicle mounted hydrogen storage vessel, reproduced from\textsuperscript{[24]}

Although compressed gaseous storage of hydrogen is one of the most viable option s for storage of hydrogen, the issue of high cost of storage due to costly multistage compression cycles and safety concerns which arises due to high pressure storage limits its rapid commercial deployment. In addition, compressed gaseous storage of hydrogen is volumetrically and gravimetrically\textsuperscript{[25]}.

#### 2.2.2 Liquid Storage of Hydrogen

This mechanism of storing hydrogen involves compression which then followed by liquefaction at cryogenic condition during which temperature of the gas is reduced to -252°C at vacuum conditions\textsuperscript{[24]}. Herein, low tempera-
ture liquid is stored in a thermally insulated container (that can store 0.070 kg/L of hydrogen, even more than CNG tanks which store 0.030 kg/L\textsuperscript{[26]} for storage and transportation. As a result of the conditions at which liquid hydrogen stored, it possesses high energy density (mass and volume density) and content (8.4 MJ/L). However, liquid storage of hydrogen is faced with technical challenges that limit its commercial deployment. Firstly, it is energy intensive as a result of energy needed for liquefaction process (it is reported that liquefaction is equal to 30% of the total hydrogen energy in practical applications). Secondly, thermal insulation of hydrogen storage vessels is difficult to attain to meet specific requirements such design of special materials to be used for insulation and design of the storage vessel. Furthermore, the compulsory venting process in FCVs referred to as Dormancy\textsuperscript{[27]} poses serious challenge to its practical applications.

2.2.3 Solid-state Storage

Solid-state storage involves using metal hydrides, complex hydride metals (borohydride) and other materials of high surface for hydrogen storage. This mechanism of storage follows two routes; (i) absorption of hydrogen atoms on metal hydrides via chemical bonds and (ii) adsorption of hydrogen atoms on the high surface area of materials (adsorbents). For metal hydrides, dihydrogen bonds formed when metal hydride (M - H) accept protons from protic hydrogen moiety (H - X) to form metal complexes (M-H···H-X)\textsuperscript{[28]} as shown in Figure 8 are responsible for hydrogen storage in their framework. The viability with which hydrogen is stored in metal hydrides makes the process intrinsically safe with volumetric capacity higher than that of compressed gaseous and liquid storage of hydrogen\textsuperscript{[29]}. Also, metal hydrides possess ability to reversibly store and release (at room temperatures) hydrogen at high storage capacity (5 - 7 wt%)\textsuperscript{[30]}, such storage capacity is obtainable at temperatures of 2500°C or higher.

For adsorbents, physisorption is responsible for facilitating storage of hydrogen. In this regard, target gravimetric storage capacities become attainable at low pressures in adsorbents such as carbon nanotubes, activated carbon, graphene containing materials and MOFs etc. Hence, use of adsorbents in cryo-adsorption tanks for improved hydrogen storage at pressures of 350 bar and cryogenic temperatures has become a reality in some prototype fuel cell vehicles produced by BMW. Also, adsorption storage of hydrogen is a fully reversible and rapid process that is hinged on van der Waals force (although other forces such as orbital interactions and electrostatic attraction may influence the process of adsorption\textsuperscript{[31]} hence its heat of adsorption is low translating to ease of management of the process as regards energy consumption for regeneration. In addition, adsorbents investigated for hydrogen storage have been reported to exhibit properties such as ease of functionalization for improved adsorption capacity, mechanical, thermal and chemical stability and good regenerability. Therefore, storage of hydrogen on adsorbents, particularly MOFs (which exhibit exceptional storage capacity for hydrogen at low pressures and temperatures closer to ambient than liquid storage) become attractive as a compound that can meet DOE’s target for adsorbed storage of hydrogen. Hence, review of MOFs for hydrogen storage would be focus also be the focus of this review as metal hydrides face challenges such as high cost of high purity metals used in the production of hydrides and the non-reversibility of hydrogen uptake by these compounds.

3. Metal Organic Framework (MOF)

Metal-organic frameworks (MOFs) are an exciting and emerging class of porous materials constructed from metal-containing nodes [also known as secondary building units (SBUs)] and organic linkers (ligands) reacted in a solution\textsuperscript{[32]} - basic pathway of synthesis is shown in Figure 9. After synthesis, removal of the solvent produces a porous network that is crystalline whose topology is controlled by the symmetry and coordination of building constituents of the framework. Also, MOFs usually boast a structure with permanent porosity and open crystalline networks due to the presence of strong bonds that exist between SBUs and organic linkers. In addition, these SBUs and ligands can be altered to control pore sizes and surface area of the framework which would influence the availability of active sites for guest molecules adsorption. In this vein, MOFs with properties such as high surface area (up to 10000 m\textsuperscript{2}/g), high porosity (up to 90%) and tunable pore sizes for gas storage and separation have been reported\textsuperscript{[33]}.

Figure 8. Diagrammatic representation of hydrogen storage in metal hydrides, modified from\textsuperscript{[26]}

DOI: https://doi.org/10.30564/jees.v2i2.2642
Figure 9. Structure and composition of Metal Organic Framework [32]

Furthermore, the ease with which SBUs and organic inkers are altered, selected and functionalized has led to the synthesis of various types and structures of MOFs for gas storage. In this regard, structure and properties of MOFs can then be easily designed and systematically tuned by the judicious choice of building blocks [32], a feat that is rather difficult to achieve in other porous compounds such as zeolites, activated carbon, polymers etc. Hence, MOF have been shown to outperform other traditional porous materials in terms of tunability, ease of functionalization and synthesis for process applications such as gas (methane and hydrogen) storage and separation. Lozano-Castelló et al. corroborated this by stating that while traditional zeolites exhibit methane uptake below 100 cm$^3$ (STP) cm$^{-3}$ [34] (on a general note, most porous carbon materials exhibit low methane uptake capacity which according to Menon and Komarneni are in the ranges of 50 - 160 cm$^3$ cm$^{-3}$ [35]), MOFs such as HKUST-1 exhibit methane uptake of 267 cm$^3$ cm$^{-3}$ at 298K and 35 bar [36].

Due to the promising adsorption capacity of MOFs for gas storage, they have been actively investigated by different researchers for methane and hydrogen adsorption [4,7,8,37,38] so as to evaluate their use in specially designed tanks for improved gas storage abilities at low pressures and temperatures closer to ambient than those obtainable in liquefied storage option. The key to this outstanding performance of MOF is the flexible chemistry of the frameworks; these structures can be modified pre- and post- synthetically for improved methane and hydrogen performance; several methods such as open metal dense sites (OMSs), post synthetic modification [functional groups such as amino groups, pendant aldehyde and azides are incorporated into the MOF structure], post synthetic metalation[39] and post synthetic metal ion and ligand exchange have been reported as pathways through which adsorption capacity and overall performance of MOFs for gas storage can be improved.

In this vein, some MOF structures have been reported to be good candidates for methane storage while others show promising potential for hydrogen storage depending on structure design and chemistry [4]. For methane storage, such MOFs include M$_2$(dicarboxylate)-dabco frameworks [40], Zn$_4$O-based MOFs [41], 6-8, 32-34, copper carboxylates frameworks [36], MIL-series [42] and Zr-based frameworks (reported to be stable in the presence of water even though they do not exhibit storage capacity as high as benchmark MOFs in methane storage) [37] while for hydrogen storage, high performing MOFs are those that possess (1) Open metal sites (OMSs) with low coordination number (2) extra framework cations (3) ultra surface area and (4) high void fraction in the framework.

Adsorption-based Storage of Methane and Hydrogen in Tanks - MOFs Shows Capacity to Attain

For methane and hydrogen to compete with conventional energy sources such as gasoline for deployment especially in on board vehicle applications via adsorption-based tank storage, certain targets set by US Department of Energy’s (DOE) Advanced Research Projects Agency-Energy (ARPA-E) [43] and Fuel Cells Technology Office [44] have to be met. For methane, a gravimetric target has been set at 0.5 g$_{{\text{methane}}}$ g$_{-1}${sorbent} or 700 cm$^3$ (methane) g$_{-1}${sorbent} at 25°C and 65 bar translating to a volumetric capacity of 263 cm$^3$ (STP) cm$^{-3}$ when the density of methane (ρ = 0.188 g/cm$^3$ at 250 bar) is used as a reference. However, when considering a packing loss of 25% due to pelletization of MOF powder, the initial uptake capacity for methane based on the set target will have to be 330 cm$^3$ (STP) cm$^{-3}$ [4]. For hydrogen, the targets are 0.045/0.055 kg H$_2$/kg for 2020/2025 on gravimetric capacity and 1.0/1.3 kg H$_2$/L for 2020/2025 for volumetric capacity respectively at temperature range of -40/60°C as highlighted in Table 1.

Table 1. Technical targets for adsorption based hydrogen storage in light duty vehicles, adopted from [44]

<table>
<thead>
<tr>
<th>S/N</th>
<th>Storage Parameter</th>
<th>2020</th>
<th>2025</th>
<th>Ultimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Gravimetric capacity (usable specific energy from H$_2$) (kg H$_2$/kg)</td>
<td>0.045</td>
<td>0.055</td>
<td>0.065</td>
</tr>
<tr>
<td></td>
<td>Volumetric capacity (usable specific energy from H$_2$) (kg H$_2$/L)</td>
<td>1.0</td>
<td>1.3</td>
<td>1.7</td>
</tr>
<tr>
<td>2</td>
<td>Temperature of operation (°C)</td>
<td>-40/60 (sun)</td>
<td>-40/60 (sun)</td>
<td>-40/60 (sun)</td>
</tr>
<tr>
<td>3</td>
<td>Tank minimum and maximum delivery temperature of H$_2$ (°C)</td>
<td>-40/85</td>
<td>-40/85</td>
<td>-40/85</td>
</tr>
<tr>
<td>4</td>
<td>Minimum and maximum delivery pressure from storage system (bar)</td>
<td>5/12</td>
<td>5/12</td>
<td>5/12</td>
</tr>
<tr>
<td>5</td>
<td>Time for system to be filled (minutes)</td>
<td>3-5</td>
<td>3-5</td>
<td>3-5</td>
</tr>
<tr>
<td>6</td>
<td>Target loss for boil off (maximum reduction after 30 days from initial 95% of usable capacity) (%)</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>
get; methane adsorption capacity of 267 cm$^3$/cm$^3$ at 25°C and 65 bar has been reported against 330 cm$^3$/cm$^3$ at same conditions by MOF HKUST-1 [36]. The same applies for hydrogen storage - MOFs have shown deliverable adsorption capacity of 1 - 2 wt% at target process conditions, one of the closest values to DOE’s target. Nonetheless, it is important to state that hydrogen storage at atmospheric pressure (~ 1 bar) and cryogenic temperature is impractical due to the very low adsorption capacity recorded at such conditions (MOF PCN-12 is considered a benchmark that records one of the highest total hydrogen uptake of 23.2 g/L or 3.05 wt% at such conditions [45]); this can be attributed to van der Waals forces (that facilitate hydrogen-framework interaction) that become weaker at temperatures close to ambient and low pressures.

### 4. Methane and Hydrogen Adsorption Capacity of MOFs

The adsorption (herein regarded as delivery capacity) of MOF is a very important factor that influences it use for commercial applications [7]. The delivery capacity is the amount of gas stored in the adsorbent between the upper working pressure and the lower working pressure at constant/varying temperatures. For methane storage in natural gas vehicles, the engine working pressure (5 bar) is considered as the lower working pressure [46] while the upper working pressure is considered to be 65 or 35 bar as it can be actualized by using a single or two stage compressor, which is cost effective as the case maybe. Also, the upper working pressure is usually kept at higher pressures because this translates to the storage of a higher amount of methane at a particular temperature. For high pressure cryogenic hydrogen storage, its delivery pressure is set at 100 bar in line with on DOE’s target.

For methane, certain MOFs as highlighted in Table 2 have shown great promise for storage at pressures of 65 bar and 35 bar and delivery pressure at 5 bar respectively. In these MOFs, it is evident through computational studies that designing structures with ultrahigh surface areas (ranging from 2500 - 3000 m$^2$/g), void fraction of around 0.8 and optimal pore diameter of 4 - 8 Å [47] results in improved volumetric and gravimetric methane uptake. However, it is also shown that when high surface area is combined mesopores, low gravimetric uptake is reported while in the presence of high surface area and micropores, higher gravimetric uptake is recorded [48]. For volumetric uptake capacity, presence of open metal sites and pore sizes of smaller diameter strongly determine uptake capabilities. This is evident for MOF-519 [48] wherein a high volumetric capacity is recorded in the presence of limited pore sizes facilitated by BTB moieties that are partially uncoordinated 1,3,5-Tris(4-carboxyphenyl)benzene and absence of OMSs which consequently produces primary adsorption active sites are pressure of 5 bar - thereby increasing the deliverable capacity. In addition, it is reported that modification of pristine MOF with functional groups such as methyl-, ethyl- and t-butyl-groups increased methane uptake of MOFs [49].

#### Table 2. MOFs for Methane storage and delivery at 25°C

<table>
<thead>
<tr>
<th>MOF</th>
<th>Volumetric uptake (cm$^3$/g)</th>
<th>Volumetric delivery (cm$^3$/g)</th>
<th>Gravimetric uptake (g/g)</th>
<th>Gravimetric delivery (g/g)</th>
<th>Ref</th>
</tr>
</thead>
<tbody>
<tr>
<td>HKUST-1</td>
<td>267</td>
<td>211</td>
<td>190</td>
<td>150</td>
<td>[36]</td>
</tr>
<tr>
<td>MOF-519</td>
<td>259</td>
<td>200</td>
<td>210</td>
<td>151</td>
<td>[46]</td>
</tr>
<tr>
<td>Al-soc-MOF-1</td>
<td>197</td>
<td>127</td>
<td>176</td>
<td>106</td>
<td>[50]</td>
</tr>
<tr>
<td>PCN-14</td>
<td>230</td>
<td>195</td>
<td>157</td>
<td>125</td>
<td>[36]</td>
</tr>
<tr>
<td>UTSA-88a</td>
<td>248</td>
<td>204</td>
<td>185</td>
<td>141</td>
<td>[51]</td>
</tr>
<tr>
<td>Ni-MOF-74</td>
<td>251</td>
<td>228</td>
<td>129</td>
<td>115</td>
<td>[36]</td>
</tr>
<tr>
<td>MAF-38</td>
<td>263</td>
<td>226</td>
<td>187</td>
<td>150</td>
<td>[52]</td>
</tr>
<tr>
<td>NU-800</td>
<td>232</td>
<td>174</td>
<td>197</td>
<td>139</td>
<td>[49]</td>
</tr>
</tbody>
</table>

For hydrogen storage, selected MOFs have shown promising adsorption capacity (which in the true sense is the delivery capacity - difference in adsorption capacity between hydrogen uptake at ~100 bar and -196°C and hydrogen release to 5 bar and -113°C) in line with Chahine rule (increase in surface area of adsorbent results in 1 wt% excess adsorption of hydrogen) till surface area increases to ~3000 m$^2$/g [53] as shown in Figure 10. Also, highlighted in Table 3, this trend posits that gravimetric adsorption capacity of MOF is proportional to void fraction, pore size and gravimetric surface area. Gómez-Gualdrón et al. highlights this in their study in which they reported that the experimental hydrogen storage capacity of MOF she-MOF-x recorded at cryo-adsorption conditions is dependent on the pore volumes of the structure [54]. Also, heat of enthalpy plays a major role in the hydrogen adsorption capacity of MOFs - optimum heat of adsorption is stated to range from -15 to -20 KJ/mol for reasonable hydrogen storage to be achieved especially at ambient conditions [55]. Furthermore, it has been reported that introduction of OMSs into the framework and their respective alignment strongly influences hydrogen-framework interactions [45]. Finally, the presence of small pore sizes that are well...
suited for hydrogen molecules and also prompt improved overlapping potential have been reported to increase framework hydrogen uptake of MOFs [56].

![Image](image_url)

**Figure 10.** Measurement of adsorption capacity different adsorbents particularly MOF in line with Chahine rule, reproduced from [57].

**Table 3.** Deliverable hydrogen adsorption capacity in MOF at cryo-adsorption conditions (-196°C and ~100bar although (variable)) and desorption conditions (-113°C and 5 bar)

<table>
<thead>
<tr>
<th>MOF</th>
<th>SA (m²/g)</th>
<th>Volumetric capacity (g/L)</th>
<th>Gravimetric capacity (wt %)</th>
<th>Void Fraction</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>she-MOF-1</td>
<td>4300</td>
<td>43.4</td>
<td>12.5</td>
<td>-</td>
<td>[54]</td>
</tr>
<tr>
<td>NU-1103</td>
<td>6246</td>
<td>43.2</td>
<td>12.6</td>
<td>-</td>
<td>[54]</td>
</tr>
<tr>
<td>MOF-5</td>
<td>3512</td>
<td>51.9</td>
<td>7.8</td>
<td>0.81</td>
<td>[58]</td>
</tr>
<tr>
<td>IRMOF-20</td>
<td>4073</td>
<td>51</td>
<td>9.1</td>
<td>0.84</td>
<td>[58]</td>
</tr>
<tr>
<td>NU-125</td>
<td>-</td>
<td>49</td>
<td>8.5</td>
<td>-</td>
<td>[53]</td>
</tr>
<tr>
<td>SNU-70</td>
<td>4944</td>
<td>47.9</td>
<td>10.6</td>
<td>0.86</td>
<td>[58]</td>
</tr>
<tr>
<td>UMCM-9</td>
<td>5039</td>
<td>47.4</td>
<td>11.3</td>
<td>0.86</td>
<td>[58]</td>
</tr>
</tbody>
</table>

5. Computational and Molecular Simulation Studies of Methane and Hydrogen Storage

In order to abate high cost of carrying out experimental works as regards synthesis of MOFs for methane and hydrogen storage, computational design and molecular studies of hypothetical MOFs have been increasingly carried out to determine their structure-property for gas storage; a study by Gómez-Gualdrón [54] reported construction of 13512 MOFs which were evaluated for cryo-adsorption of hydrogen while Wilmer et al. reported construction of 137953 hypothetical MOFs for methane adsorption [47]. In this vein, particular attention has been paid to designing of MOFs of specific topologies that can provide active sites for guest molecules; herein careful selection of organic linkers and SBUs that are fitted to pre-determined topologies via an automated algorithm.

For construction of hypothetical MOFs, different approaches are utilized. While some researchers use a down-top approach by building the crystal structure from building blocks and SBUs till the structure is formed, others approach construction from a top-down method in which selected building blocks are connected to a pre-determined topological blueprint. For the down-top approach whose pathway is shown in Figure 11, crystallographic data of known synthesized MOFs is used to select building blocks that are combined based on local geometry and chemical composition that must be the same. The process of building continues stepwise until an atomic overlap occurs during a different building block is used and the process continues [47]. In this process, a periodic boundary formed by connecting two building blocks is sometimes imposed instead of adding a new building block. Also, minimization of force fields or quantum mechanical energy is carried in this approach - down-top approach is governed by geometric rules that synthesis of existing MOFs from various building blocks. Thereafter, validation of the hypothetical MOF is carried out; herein certain aspects of the crystal structure such as its minimum energy, fitness of hypothetical structure to those synthesized experimentally and sensitivity of physical properties of hypothetical structures to experimental ones are evaluated - physical properties usually considered are topology of framework, limiting diameter of pore sizes, diameter of largest cavity, accessible pore volume, accessible surface area, equilibrium gas loading capacity and Henry’s law constant. Hence, a comparison of the hypothetical structures with those that are energetically relaxed through minimization of force fields is carried out; same is done for experimentally synthesized MOFs. Also, predicted gas adsorption capacities of hypothetical structures are compared with those that are experimental synthesized. Significantly, it has been reported that the predicted adsorption capacity of most hypothetical MOFs are close to their experimentally synthesized counterparts as shown in Figure 12 - the values of hydrogen adsorption isotherms (measured in mmol/g) of simulated and experimental NU-125 at temperatures of -196°C, -113°C and 23°C show excellent agreement. The use of down-top approach for MOF structure construction faces the challenge of producing MOFs with limited topologies. This is reported by Sikora et al. in their work in which they revealed that out of 137000 hypotheti-
cal MOFs constructed (90% of MOFs produced), only six topologies of primitive pcu topology were produced [59]. Also, some expected topologies were not realized hence, the top-down approach becomes attractive as it been reported to ameliorate this drawback. This computational method involves matching of symmetry and connectivity of the nodes of pre-selected topology of the structures and their respective building blocks. In other works, top-down approach entails selection of the appropriate template and topology to which selected building blocks would be added in stepwise manner. This is followed by scaling of unit cells of the topology based on the targeted building block that is to be added. Hereafter, organic and inorganic nodes and organic linkers are added; the structure obtained would then be optimized using classical force field optimization. Finally, the physical properties of the hypothetical MOF are evaluated. The ability of top-down approach to produce hypothetical MOFs have been reported by Gómez-Gualdrón et al. [54]; in their work, they reported that out of 13512 MOFs constructed, 41 different topologies were recorded.

Figure 11. Pathway for construction of hypothetical MOFs in down-top approach, reproduced from [47], a - pathway for synthesis of hypothetical MOFs, b - pathway for stepwise construction of hypothetical MOFs from building blocks; purple Xs - sites of connection, hashed circle mirror images - periodic boundaries, grey - carbon atom, red sphere - oxygen atom, blue sphere - nitrogen atom, turquoise sphere - zinc atom

Figure 12. Simulated (triangles) and measured (circles) adsorption isotherms of NU-125, reproduced from [53]

6. Conclusion

The importance of clean energy sources such as methane and hydrogen for environmental sustainability and actualization of a net zero carbon emission future has been highlighted. Hence in this mini review, different mechanisms for storing methane and hydrogen in commercial applications especially on board vehicle storage to increase their storage capacities for improved performance so as to challenge conventional energy sources for deployment were discussed. Herein, suitability of adsorption-based storage of methane and hydrogen in specially designed tanks was highlighted. In this regard, MOFs were revealed as the most promising adsorbent that can achieve the ambitious targets set by US DOE’s Advanced Research Projects Agency-Energy (ARPA-E) and Fuel Cells Technology Office. Hence, selected high performing MOFs for methane and hydrogen storage were highlighted and trends of research that facilitate their occurrence were discussed. In addition, computation and molecular studies of hypothetical MOFs were discussed - trends of research in this field were discussed and methodologies to construct MOFs of designated topologies and physical properties were revealed.

References

DOI: 10.1016/j.energy.2008.08.027

DOI: 10.4028/www.scientific.net/jmnm.2-6.615

DOI: 10.1126/science.1067208

DOI: 10.1016/j.ccr.2011.02.012

DOI: 10.1002/cphc.201801147

DOI: 10.1016/S0016-2361(02)00124-2

DOI: 10.1016/S0166-2361(02)00124-2

DOI: 10.1021/ja4045289

DOI: 10.1002/ente.201700636

DOI: 10.1002/cphc.201801147

DOI: 10.1039/c4cs00076e

DOI: 10.1016/j.micromeso.2007.09.016

DOI: 10.1126/science.1067208

DOI: 10.1007/s10934-010-9371-7


DOI: 10.1002/ange.200802087

DOI: 10.1039/c3sc52633j


DOI: 10.1021/jp502359q

[50] D. Alezi, Y. Belmabkhout, M. Suyetin, P.M. Bhatt, L.J. Weseliński, V. Solovyeva, K. Adil, I. Spanopou-
Crystal Chemistry Paving the Way to Gas Storage Needs: Aluminum-Based MOF for CH4, O2, and CO2 Storage. J. Am. Chem. Soc., 2015, 137: 13308-13318. DOI: 10.1021/jacs.5b07053


Author Guidelines

This document provides some guidelines to authors for submission in order to work towards a seamless submission process. While complete adherence to the following guidelines is not enforced, authors should note that following through with the guidelines will be helpful in expediting the copyediting and proofreading processes, and allow for improved readability during the review process.

Ⅰ. Format

- Program: Microsoft Word (preferred)
- Font: Times New Roman
- Size: 12
- Style: Normal
- Paragraph: Justified
- Required Documents

Ⅱ. Cover Letter

All articles should include a cover letter as a separate document. The cover letter should include:

- Names and affiliation of author(s)
  The corresponding author should be identified.
  Eg. Department, University, Province/City/State, Postal Code, Country
- A brief description of the novelty and importance of the findings detailed in the paper

Declaration

v Conflict of Interest

Examples of conflicts of interest include (but are not limited to):

- Research grants
- Honoria
- Employment or consultation
- Project sponsors
- Author’s position on advisory boards or board of directors/management relationships
- Multiple affiliation
- Other financial relationships/support
- Informed Consent

This section confirms that written consent was obtained from all participants prior to the study.

- Ethical Approval
  Eg. The paper received the ethical approval of XXX Ethics Committee.
- Trial Registration
  Eg. Name of Trial Registry: Trial Registration Number
Contributorship

The role(s) that each author undertook should be reflected in this section. This section affirms that each credited author has had a significant contribution to the article.

1. Main Manuscript
2. Reference List
3. Supplementary Data/Information

Supplementary figures, small tables, text etc.

As supplementary data/information is not copyedited/proofread, kindly ensure that the section is free from errors, and is presented clearly.

III. Abstract

A general introduction to the research topic of the paper should be provided, along with a brief summary of its main results and implications. Kindly ensure the abstract is self-contained and remains readable to a wider audience. The abstract should also be kept to a maximum of 200 words.

Authors should also include 5-8 keywords after the abstract, separated by a semi-colon, avoiding the words already used in the title of the article.

Abstract and keywords should be reflected as font size 14.

IV. Title

The title should not exceed 50 words. Authors are encouraged to keep their titles succinct and relevant.

Titles should be reflected as font size 26, and in bold type.

IV. Section Headings

Section headings, sub-headings, and sub-subheadings should be differentiated by font size.

Section Headings: Font size 22, bold type
Sub-Headings: Font size 16, bold type
Sub-Subheadings: Font size 14, bold type

Main Manuscript Outline

V. Introduction

The introduction should highlight the significance of the research conducted, in particular, in relation to current state of research in the field. A clear research objective should be conveyed within a single sentence.

VI. Methodology/Methods

In this section, the methods used to obtain the results in the paper should be clearly elucidated. This allows readers to be able to replicate the study in the future. Authors should ensure that any references made to other research or experiments should be clearly cited.

VII. Results

In this section, the results of experiments conducted should be detailed. The results should not be discussed at length in
this section. Alternatively, Results and Discussion can also be combined to a single section.

VIII. Discussion

In this section, the results of the experiments conducted can be discussed in detail. Authors should discuss the direct and indirect implications of their findings, and also discuss if the results obtain reflect the current state of research in the field. Applications for the research should be discussed in this section. Suggestions for future research can also be discussed in this section.

IX. Conclusion

This section offers closure for the paper. An effective conclusion will need to sum up the principal findings of the papers, and its implications for further research.

X. References

References should be included as a separate page from the main manuscript. For parts of the manuscript that have referenced a particular source, a superscript (ie. \[x\]) should be included next to the referenced text.

\[x\] refers to the allocated number of the source under the Reference List (eg. [1], [2], [3])

In the References section, the corresponding source should be referenced as:

\[x\] Author(s). Article Title [Publication Type]. Journal Name, Vol. No., Issue No.: Page numbers. (DOI number)

XI. Glossary of Publication Type

\[ \text{J} = \text{Journal/Magazine} \]
\[ \text{M} = \text{Monograph/Book} \]
\[ \text{C} = \text{(Article) Collection} \]
\[ \text{D} = \text{Dissertation/Thesis} \]
\[ \text{P} = \text{Patent} \]
\[ \text{S} = \text{Standards} \]
\[ \text{N} = \text{Newspapers} \]
\[ \text{R} = \text{Reports} \]

Kindly note that the order of appearance of the referenced source should follow its order of appearance in the main manuscript.

Graphs, Figures, Tables, and Equations

Graphs, figures and tables should be labelled closely below it and aligned to the center. Each data presentation type should be labelled as Graph, Figure, or Table, and its sequence should be in running order, separate from each other. Equations should be aligned to the left, and numbered with in running order with its number in parenthesis (aligned right).

XII. Others

Conflicts of interest, acknowledgements, and publication ethics should also be declared in the final version of the manuscript. Instructions have been provided as its counterpart under Cover Letter.
Journal of Environmental & Earth Sciences

Aims and Scope

Journal of Environmental & Earth Sciences is a peer-reviewed, open-access academic journal specializing in the research of environmental geoscience. The journal is dedicated to promoting the latest discoveries in the field of environmental & earth sciences.

The scope of the Journal of Environmental & Earth Sciences includes, but is not limited to:

- Geological and hydrogeological resources
- Geomorphology
- Edaphology
- Geochemical, geological, geophysical principles
- Environmental problems

Bilingual Publishing Co. (BPC)

Tel: +65 65881289

E-mail: contact@bilpublishing.com

Website: www.bilpublishing.com
About the Publisher

Bilingual Publishing Co. (BPC) is an international publisher of online, open access and scholarly peer-reviewed journals covering a wide range of academic disciplines including science, technology, medicine, engineering, education and social science. Reflecting the latest research from a broad sweep of subjects, our content is accessible worldwide—both in print and online.

BPC aims to provide an analytics as well as platform for information exchange and discussion that help organizations and professionals in advancing society for the betterment of mankind. BPC hopes to be indexed by well-known databases in order to expand its reach to the science community, and eventually grow to be a reputable publisher recognized by scholars and researchers around the world.

BPC adopts the Open Journal Systems, see on ojs.bilpublishing.com

Database Inclusion

- APSCI: Asia & Pacific Science Citation Index
- Creative Commons
- CNKI: China National Knowledge Infrastructure
- Google Scholar
- CrossRef
- MyScienceWork