P - ISSN : 2722 - 0133
E - ISSN : 2722 - 0141

Indonesian Journal of Applied Environmental Studies

Volume 5 • Number 2 • October 2024

Co-Published by

Pakuan University

Cover Photo : *Nyctixalus margaritifer*, also known as the Java Indonesian treefrog and pearly tree frog, is a species of frog in the family Rhacophoridae. It is endemic to Java, Indonesia, where it is known from a number of records at elevations above 700 m (2,300 ft) (©Saeful Mahdi).

Published biannually

P-ISSN: 2722 - 0133 E-ISSN: 2722 - 0141

9 772722 013002 9 772722 014009

Indonesian Journal of Applied Environmental Studies

P - ISSN: 2722 - 0133 (printed edition)
E - ISSN: 2722 - 0141 (electronic)
Graduate School of Environmental Management
Pakuan University
Jl. Pakuan, Kotak Pos 425 Bogor
Telp / Fax: (0251) 8320123
Web: www.unpak.ac.id
Email: ml.pasca@unpak.ac.id

Co-Publishers:

Indonesian Association of Environmentalist Scholars or Perhimpunan Cendikiawan Pemerhati Lingkungan Indonesia (PERWAKU) and Graduate School of Environmental Management, Pakuan University

Supporters:

Belantara Foundation and Relawan Jurnal Indonesia

The Indonesian Journal of Applied Environmental Studies is co-published by Graduate School of Environmental Management, Pakuan University, Indonesia and Perhimpunan Cendikiawan Pemerhati Lingkungan Indonesia (PERWAKU) in collaboration with Belantara Foundation. It is an open access journal available at: **https://journal.unpak.ac.id/index.php/InJAST/index**

Indonesian Journal of Applied Environmental Studies (InJAST) would like to express its gratitude to the people below for their invaluable services as peer-reviewers on this issue of the journal:

Adi Susilo, M.Sc. (*Indonesia*)
Dr. Chittaranjan Baruah, M.Sc. (*India*)
Dr. Dolly Priatna (*Indonesia*)
Lan Qie, Ph.D. (*United Kingdom*)
Laura D'Arcy, M.Sc. (*United Kingdom*)
M. Nazre Saleh, Ph.D. (*Malaysia*)
Prof. Dr. M. Monirul H. Khan, Ph.D. (*Bangladesh*)
Dr. Rita Retnowati (*Indonesia*)
Dr. Rosadi (*Indonesia*)
Prof. Dr. Wahyu Widiyono (*Indonesia*)
Dr. Yossa Istiadi (*Indonesia*)

InJAST's website and online submission portal is:
https://journal.unpak.ac.id/index.php/InJAST/index

Submissions can also be directed to the Chief Editors at: **injast@unpak.ac.id**

Comments on InJAST's website, reporting portal issues and other issues, should be addressed to the Editorial Manager at: **editor_injast@unpak.ac.id**

InJAST
Volume 5, Number 2, October 2024
Pages: 55-57

P - ISSN: 2722 - 0133
E - ISSN: 2722 - 0141
DOI: 10.33751/injast.v5i2.10901

GUEST EDITORIAL

Indonesian green tides: the problem is also the solution

CHRISTINE A. MAGGS[1,*], DAVID HARRIES[2], DOLLY PRIATNA[3]

[1]School of Biological Sciences, Queen's University Belfast, 19 Chlorine Gardens, Belfast BT9 5DL, United Kingdom
[2]Somerton Cottage, Hundleton, Pembroke SA71 5RX, United Kingdom
[3]Graduate School of Environment Management, Pakuan University, Jl. Pakuan No. 1, Tegallega, Bogor 6129, Indonesia

[*]Corresponding author: *christine.a.maggs@gmail.com*

Submitted 9 October 2024; Accepted 31 October 2024

INTRODUCTION

Green tides are unattached blooms of green macroalgae (seaweeds) that occur globally and can attain vast proportions. The main components of the blooms are species of the sea lettuce genus *Ulva*, a sheet-like green seaweed, which can form unusual morphs under these conditions (Blomster et al., 2002). In estuaries and shallow coastal embayments drifting or cast-up macroalgae can reach quantities of up to 27 kg wet weight m^{-2}. Green tides have been researched extensively since Fletcher's (1996) review highlighted their importance, but they came to wide public attention at the time of the 2008 Qingdao Summer Olympics when the Yellow Sea blooms endangered the sailing events. In May–July 2008, prior to the Olympics, the Yellow Sea coastline experienced the world's largest green tide with 1 million tonnes of drifting biomass covering 13,000–30,000 km^2 (Leliaert et al., 2008). Enormous quantities were washed into shallow water and onto the beaches. News reports from the time show volunteers working to remove the biomass and save the events. Green tides have increased in frequency and extent globally over the last few decades, with the most significant blooms continuing to be those in the Yellow Sea (Ye et al., 2011; Ren et al., 2024).

GREEN TIDES: THE PROBLEM

The Ulvophyceae, the most abundant and widespread macroalgae of the blooms, exhibit rapid nutrient uptake and growth rates, nutrient exploitation and storage strategies that clearly contribute to their propensity to produce blooms in nutrient rich shallow waters (Fletcher, 1996). Green tides can persist for up to a dozen years, and can pervasively and fundamentally alter ecosystems.

Green tide blooms undergo sudden explosions followed by catastrophic collapses in late spring or early summer. Degradation of the algal biomass causes complete anoxia and the accumulation of toxic hydrogen sulfide, which results in mass mortality of fauna (including terrestrial animals walking on the shore) and displacement of natural communities of plants and algae. Assemblages of sediment-dwelling fauna are damaged, reducing their biodiversity and their functionality as nutrient recyclers, mixers of sediment and their provision of an important source of food for fish and aquatic birds. Green tides can directly disrupt the feeding of wading birds, which are typically highly protected by environmental legislation (Raffaelli et al., 1998).

In addition to their environmental impacts, macroalgal blooms and their collapse and dystrophic crises also affect human uses of the coastal marine environment. Impacts include interference with fishing and aquaculture activities, and fish and shellfish mortalities due to hypoxia. The Yellow Sea green tide in 2008 caused direct economic losses due to damage to aquaculture, killing prawns and shellfish worth c. €86 million; the clean-up for the sailing event had an estimated cost of €200 million (Ye et al., 2011).

Green tides have significant effects on the major biogeochemical cycles of C, N, P and S. The algal mats stimulate ammonium and phosphate release that promotes their growth. During green tides, macroalgae sequester nutrients otherwise available for other primary producers (Valiela et al., 1997).

GREEN TIDES: THE CAUSE

The occurrence of green tides globally is linked to eutrophication, the increased nitrogen and phosphorus levels in coastal waters caused by human activities. Eutrophication is usually due to nutrients from agriculture. For example, in Denmark, more than 60% of the surface is agricultural, and 13 million pigs are produced p.a. (Bruhns, Aarhus University, conference abstract). In Britanny, France, the green tides due to nutrient inflows from pig farming have occurred over several decades, such that there is a recent French movie about them "Les algues vertes: 3 men and 40 animals were found dead on the Breton beaches ... a young journalist, driven by an ecological conscience, decides to go to Brittany to investigate".

In Europe, eutrophication is subject to control by the Nitrates Directive (with a derogation for agriculture in Ireland!!), and is regulated and monitored under the Water Framework Directive (2000/60/EC). The WFD focuses on the overall ecology and function of ecosystems in a holistic approach to the management of rivers, lakes, transitional and coastal waters. Significant pressures on water bodies must be identified and quantified - these include habitat loss, hazardous chemicals and eutrophication. Macroalgae form one biological quality element, and tools developed for coastal and transitional waters to determine eutrophication include monitoring mats of bloom-forming algae on sedimentary shores using both macroalgal biomass and cover to determine ecological status (Scanlan et al., 2007). High (reference) status is defined as <5% cover and <100 g m-2 on shore (so the green tides are clearly outside these values).

Internationally, the indicators for one of the UN's SDGs, 14. Life below water, refer specifically to "Coastal eutrophication: a growing threat to marine ecosystems and communities. Agriculture, aquaculture and wastewater practices are contributing to nutrient loading in coastal areas, causing widespread coastal eutrophication and algal blooms. These blooms lead to oxygen depletion, harm marine life, contaminate seafood, and damage seagrass and coral reefs, among other impacts. The consequences are severe for marine ecosystem health, local communities, fisheries and tourism."

GREEN TIDES: THE SOLUTION

The significant ecological, economical and social consequences of macroalgal blooms and dystrophy have caused considerable concern and resulted in the implementation of various attempted control measures. These management interventions fall into three main categories: algal harvesting, reduction of nutrient loads and improvements of water circulation to promote removal of nutrients and algal biomass. Implementation of these management strategies is extremely expensive (Fletcher, 1996), involving the removal of about 100,000 tonnes of seaweed per annum from recreational beaches of Atlantic France alone (Dion & Le Bozec, 1996). Also, they are often in response to specific catastrophic events, like the 2008 Yellow Sea bloom, and usually have had only limited success (Ye et al., 2011).

Over the last two decades, however, the increasing biotechnological value of *Ulva* species means that the vast biomass present in green tides can serve as valuable inputs for biorefineries, facilitating the production of fertilizers, biofuels, chemicals, food ingredients, and pharmaceuticals, horticulture and industrial applications (Ren et al., 2024). When the blooms are harvested this can potentially remove nutrients, restore habitats, and provide a cheap ingredient. *Ulva* species, particularly *Ulva lactuca*, are gaining popularity in a variety of industrial applications due to their high bioactive content and environmental benefits. These applications include uses in food, medicine, aquaculture, and environmental management, with potential for further growth.

Currently, *Ulva* species are used in the food industry as a healthy food source due to their high vitamin, mineral, and bioactive component content, which contributes to health advantages such as antioxidant and anti-inflammatory qualities. In pharmaceuticals, extracting bioactive chemicals from *Ulva* has the potential to aid in therapeutic development, notably for cardiovascular and neuroprotective health (Putra et al., 2024). *Ulva* is used in aquaculture as a natural growth promoter and immunological stimulant, answering the demand for long-term alternatives to antibiotics. Furthermore, in environmental management these algae can reduce nutrient pollution in coastal habitats, hence contributing to ecosystem restoration and sustainability (Blomme et al., 2023). In mariculture, *Ulva* is being explored as a model organism for sustainable mariculture, potentially revolutionizing coastal economies and food security (Buck & Shpigel, 2023).

GREEN TIDES: THE INDONESIA

The reviews of the global occurrence of green tides by Ye et al. (2011) and Ren et al (2024) do not mention any green tides in Indonesia, hence they appear not to have been reported frequently. However, as might be expected for a heavily populated coastline, green tides do occur in Indonesia. Ocean Harvest Technology's OceanFeed, a patented blend of red, green and brown seaweed formulated to support the healthy microbiome of livestock (https://oceanharvesttechnology.com), uses green tide *Ulva* mostly from Vietnam and Indonesia, and to a lesser extent from Zanzibar, in constituting its animal feed supplement.

To determine which species of bloom-forming species of *Ulva* are harvested in Indonesia, we obtained air-dried material of OHT's samples from Indonesia, Vietnam and Zanzibar. They were rehydrated in fresh water for morphological examination and for the preparation of voucher specimens.

Use of molecular identification methods is essential in *Ulva* owing to high morphological variability and lack of stable features. For this purpose, DNA was extracted in the Harries private lab and the *rbcL* gene (a chloroplast-encoded gene widely used for red and green algal systematics) was amplified and commercially sequenced as described by Maggs et al. (2004) (Figure 1). The Indonesian green tide samples were identified as *Ulva ohnoi*, a species originally described from Japan, that forms green tides throughout much of the world's tropical and warm-temperate coastal areas. The thalli are fragile but grow fast with rapid photosynthesis (Nakamura et al., 2019). The proliferation of *Ulva ohnoi* can lead to hypoxia and negatively affect marine biodiversity, similar to the impacts observed with *Ulva prolifera* blooms in other regions (Dong et al., 2023; Hiraoka, 2021).

In contrast, *Ulva ohnoi* presents ecological challenges; however, it can also offer advantages, including habitat for marine organisms and potential applications in aquaculture and biomass production. Consequently, the necessity of balanced management strategies is underscored.

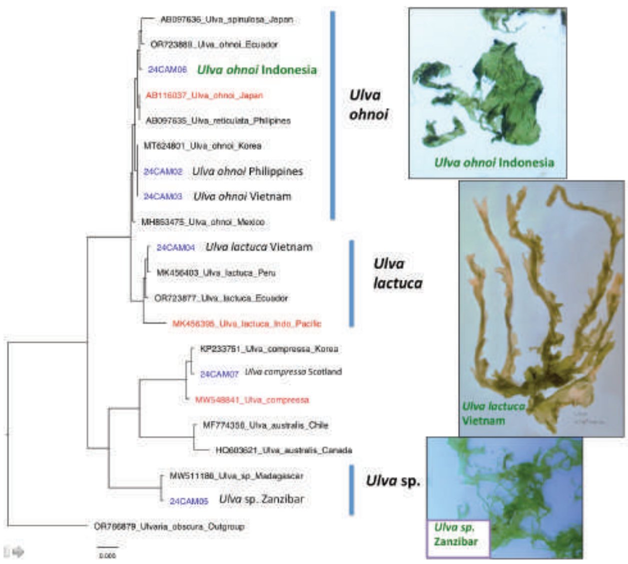

Figure 1. Analyses of *rbcL* gene sequences of *Ulva* from around the world, mostly in GenBank, showing their phylogenetic position and identification. CAM samples (codes in blue) from Indonesia, Vietnam and Zanzibar (purchased by Ocean Harvest Technology and newly sequenced) are identified as three different species, each with a clearly distinct morphology (images on right).

CONCLUSION

Green tides, primarily *Ulva* species, are unattached blooms of green macroalgae that affect ecosystems globally. They can reach up to 27 kg wet weight m-2 and persist for up to a dozen years. The most significant blooms occur in the Yellow Sea, causing economic losses and disruptions in fishing and aquaculture activities. Green tides are linked to eutrophication, which increases nitrogen and phosphorus levels in coastal waters. However, the vast biomass in green tides can be used for biorefineries, fertilizers, biofuels, chemicals, food ingredients, pharmaceuticals, horticulture, and industrial applications. Ulva species are also being explored as a model organism for sustainable mariculture, potentially revolutionizing coastal economies and food security.

ACKNOWLEDGEMENTS

Basil Kennedy (Ocean Harvest Technology) kindly supplied the seaweed.

REFERENCES

Blomme, J., Wichard, T., Jacobs, T., & DeClerck, O. (2023). *Ulva*: An emerging green seaweed model for systems biology. *Journal of Phycology, 59(3): 433-440.* doi: 10.1111/jpy.13341

Blomster, J., Back, S., Fewer, D.P., Kiirikki, M., Lehvo, A., Maggs, C.A. & Stanhope, M.J. (2002). Green tide conditions trigger novel morphology in *Enteromorpha*. *American Journal of Botany, 89:1756-1763*.

Bruhn, A. Conference abstract. Aarhus University.

Buck, B.H., & Shpigel, M. (2023). ULVA: Tomorrow's "Wheat of the sea", a model for an innovative mariculture. *Journal of Applied Phycology, 35(5): 1967-1970*. doi: 10.1007/s10811-023-03003-1

Dion, P., & Le Bozec, S., 1996. *The French Atlantic coasts*. In: Schramm, W., Nienhuis, P.H. (Eds.), Marine Benthic Vegetation: Recent Changes and the Effects of Eutrophication. Springer, Berlin, pp. 251–264.

Dong, S., Xin, Y., Liu, C., Xiao, Y., Feng, X., & Liu, T. (2023). Two treatment methods on *Ulva prolifera* bloom result in distinctively different ecological effects in coastal environment. *Frontiers in Marine Science, 10: 1084519*. doi: 10.3389/fmars.2023.1084519

Fletcher, R.L. (1996). *The occurrence of "green tides"- a review*. In: Schramm, W. & Nienhuis, P.H. (Eds.). Marine benthic vegetation: Recent changes and the effects of eutrophication. Ecological Studies 123. Springer-Verlag, Berlin. pp. 7-43.

Hiraoka, M. (2021). Massive *Ulva* green tides caused by inhibition of biomass allocation to sporulation. Plants, 10 (11): 2482. doi: 10.3390/PLANTS10112482

Leliaert, F., Malta, E.J., Engelen, A.H., Mineur, F., & De Clerck, O. (2008). Qingdao algal bloom culprit identified. *Marine Pollution Bulletin, 56: 15–16*.

Maggs, C.A., Bunker, A.R., Bunker, F.St.P.D., Harries, D., Kelly, J., Mineur, F., Blomster, J., Díaz-Tapia, P., Gabrielson, P.W., Hughey, J.R., & Brodie, J. (2024). Updating the Ulvaceae in the green seaweeds of Britain and Ireland. *Botanica Marina, 67: 1–20*.

Nakamura, M., Kumagai, N.H., Tamaoki, M., Arita, K., Ishii, Y., Nakajima, N., & Yabe, T. (2019). Photosynthesis and growth of *Ulva ohnoi* and *Ulva pertusa* (Ulvophyceae) under high light and high temperature conditions, and implications for green tide in Japan. *Phycological Research, 68: 152-160*.

Putra, N.R., Fajriah, S., Qomariyah, L., Dewi, A.S., Rizkiyah, D.N., Irianto, I., Rusmin, D., Melati, M., Trisnawati, N.W., Darwati, I., & Arya, N.N. (2024). Exploring the potential of *Ulva lactuca*: Emerging extraction methods, bioactive compounds, and health applications – A perspective review. *South African Journal of Chemical Engineering, 47: 233-245*. doi: 10.1016/j.sajce.2023.11.017

Raffaelli, D.G., Raven, J.A., & Poole, L.J. (1998). Ecological impact of green macroalgal blooms. *Oceanography and Marine Biology, 36: 97-125*.

Ren, C., Zhong, Z., Liu, Z., Lin, S., Luo, Y., & Qin, S. (2024). The ever-lasting green tides: What can we do?. *Heliyon, 10 (3): e25220*. https://doi.org/10.1016/j.heliyon.2024.e25220

Scanlan, C.M., Foden, J., Wells, E., & Best, M.A. (2007). The monitoring of opportunistic macroalgal blooms for the Water Framework Directive. *Marine Pollution Bulletin, 55: 162-171*.

Valiela, I., McClelland, J., Hauxwell, J., Behr, P.J., Hersh, D., & Foreman, K. (1997). Macroalgal blooms in shallow estuaries: Controls and ecophysiological and ecosystem consequences. *Limnology and Oceanography, 42: 1105-A1118*.

Ye, N., Zhang, X., Mao, Y., Liang, C., Xu, D., Zou, J., Zhuang, Z., & Wang, Q. (2011). 'Green tides' are overwhelming the coastline of our blue planet: taking the world's largest example. *Ecological Research, 26: 477-485*. https://doi.org/10.1007/s11284-011-0821-8.

InJAST
Volume 5, Number 2, October 2024
Pages: 58-64

P - ISSN: 2722 - 0133
E - ISSN: 2722 - 0141
DOI: 10.33751/injast.v5i2.10721

Utilization of Digital Terrain Model (DTM) from LiDAR data for flood inundation simulation due to Ciujung River overflow in Banten Province

YUDI FIRMANSYAH*, MOHAMAD MAHFUDZ, RIAN NURTYAWAN

Department of Geodetic Engineering, Pakuan University, Bogor, 16143, Indonesia

*Corresponding author: *firmansyah7474@gmail.com*

Submitted 12 September 2024; Accepted 29 October 2024

ABSTRACT

Flood phenomena are natural disasters that are still difficult to predict due to climate change. Climate change has caused rainfall to become extreme, leading to floods as the water discharge exceeds river capacity. The Ciujung River is one of the major rivers in Banten Province. In 2012, the Ciujung River overflowed, cutting off access to the Tangerang-Merak Toll Road. This study utilizes a Digital Terrain Model (DTM) derived from LiDAR data and HEC-RAS software to simulate flood inundation due to the overflow of the Ciujung River in Banten. LiDAR data provides a high-resolution DTM, offering detailed and accurate topographic information. Using HEC-RAS, a hydraulic model was created to simulate water flow and potential flood inundation along the river. The simulation method refers to the Saint-Venant equations with an iterative procedure known as the standard step method. The simulation results show reliable flood depth and inundation spread as a reference for flood disaster mitigation planning. The final result of this study is a flood inundation map that provides a clear picture of flood risk levels along the Ciujung River, which can be used by local governments and other stakeholders for decision-making. From 12 flood inundation sample points, 60% were validated based on respondents' feedback. The area affected by flood hazards along the Ciujung River increased with rising water discharge, with the largest area being 109.06 hectares when the discharge reached 3000 m^3/s.

ABSTRAK

Fenomena banjir merupakan bencana alam yang masih sulit diprediksi akibat perubahan iklim. Perubahan iklim menyebabkan curah hujan menjadi ekstrem sehingga menyebabkan banjir karena debit air melebihi kapasitas sungai. Sungai Ciujung merupakan salah satu sungai besar yang ada di Provinsi Banten. Pada tahun 2012, Sungai Ciujung meluap sehingga memutus akses Tol Tangerang-Merak. Penelitian ini memanfaatkan Digital Terrain Model (DTM) yang berasal dari data LiDAR dan software HEC-RAS untuk melakukan simulasi genangan banjir akibat meluapnya Sungai Ciujung di Banten. Data LiDAR menyediakan DTM resolusi tinggi, menawarkan informasi topografi yang detail dan akurat. Dengan menggunakan HEC-RAS, model hidrolik dibuat untuk mensimulasikan aliran air dan potensi genangan banjir di sepanjang sungai. Metode simulasi mengacu pada persamaan Saint-Venant dengan prosedur iteratif yang dikenal dengan metode langkah standar. Hasil simulasi menunjukkan kedalaman banjir dan sebaran genangan yang dapat diandalkan sebagai acuan perencanaan mitigasi bencana banjir. Hasil akhir dari penelitian ini adalah peta genangan banjir yang memberikan gambaran jelas tingkat risiko banjir di sepanjang Sungai Ciujung, yang dapat digunakan oleh pemerintah daerah dan pemangku kepentingan lainnya dalam pengambilan keputusan. Dari 12 titik sampel genangan banjir, 60% tervalidasi berdasarkan masukan responden. Luas wilayah yang terkena bahaya banjir di sepanjang Sungai Ciujung bertambah seiring dengan meningkatnya debit air, dengan luas terluas 109,06 hektar dengan debit mencapai 3000 m^3/s.

Keywords: *DTM, LiDAR, HEC-RAS, Ciujung River, Banten Province*

INTRODUCTION

Floods is a natural phenomenon that can occur throughout the globe, and it is one of the most frequent natural disasters in Indonesia, have significant impacts on communities and the environment (Istiadi & Priatna, 2021). The complexity of flood events is triggered by a combination of various factors, including hydrometeorological, topographical, geological, soil, and human activities (Nucifera & Putro, 2018; Mahfudz et al., 2022). One hydrometeorological disaster is flooding due to rainfall. Excessive rainfall occurred in most parts of Indonesia throughout 2010, even during the dry season from June to August (Yulihastin, 2011). Flooding is a natural phenomenon that frequently occurs in various regions, especially in areas with high rainfall and inadequate water management systems. Scientifically, floods can be defined through two main concepts: 1) river water overflow caused by river discharge exceeding the river's capacity during high rainfall, 2) inundation in flat lowland areas that are usually not flooded (Ariyora et al., 2015; Mahfudz et al., 2024). Almost every region in Indonesia has experienced floods due to river overflow, such as in the Ciujung River Basin (DAS) in Banten.

The degradation of the Ciujung River Basin, due to increasing population pressure and economic activities, has led to changes in land use. The degradation is indicated by decreasing water discharge during the dry season. In the rainy season, extreme discharge increases along with the runoff coefficient, causing floods. Additionally, river narrowing and sedimentation from uncontrolled deposits harm communities living along the Ciujung River (Chalid et al., 2022). Based on land cover maps, from 2006-2016, forest areas in the Ciujung River Basin decreased from 10,507.89 hectares to 10,209.68 hectares, while residential areas increased (from 6,923.73 hectares to 9,537.65 hectares) and agricultural land (from 149,829.49 hectares to 161,283.69 hectares). From 2013-2018, land use changes occurred in the Upper Ciujung Sub-basin, with secondary dryland forest area percentage decreasing from 3.04% to 1.00% of the total sub-basin area, while dryland farming, mixed dryland farming, and residential areas increased (Naitkakin et al., 2023).

METHODS

Research Location

The study was conducted in the Ciujung River Basin (DAS) in Banten Province, specifically along the river crossing parts of Kibin Sub-district and Kragilan Sub-district in Serang Regency (Figure 1). The Ciujung River Basin is geographically located at 5°57'14"- 6°4'20" S and 106°01'00" - 106°29'03" E. The Ciujung River is one of the trans-provincial rivers in West Java and Banten provinces. It originates from Mount Karang and Mount Halimun, flowing northward through Bogor Regency, Lebak Regency, Serang Regency, and ending in the Java Sea estuary.

Figure 1. Research Location.

Spatial analysis is highly effective in processing and analyzing data, thereby speeding up the decision-making process in the field under study. In this research, data collection is the first step, followed by data analysis to obtain results and validation processes. For clarity, the data processing steps can be seen in the flow diagram in Figure 2.

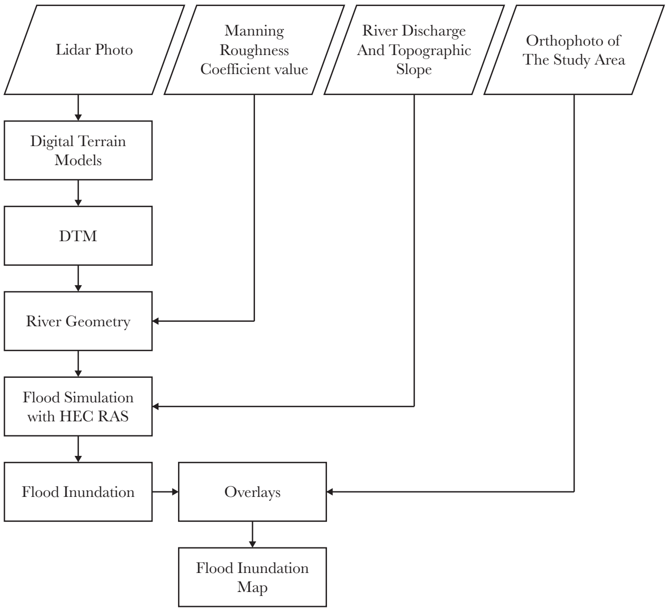

Figure 2. Research flow diagram.

LiDAR and DTM Formation

LiDAR data generates a significant amount of point cloud data, necessitating classification to understand the relationships and correlations among these points. Classification is the process of grouping points into several classes based on physical similarities, distribution areas, and characteristics relative to their needs (Asriyah et al., 2017). The desired result is a Digital Terrain Model (DTM); therefore, the automatic classification results in point cloud data that must distinguish between ground (surface) and non-ground (objects above the surface) classes. However, based on automatic classification results, some point clouds still do not fit their classes. This can be identified by overlaying the classified point cloud with orthophotos of the research area and examining the cross-sectional profile of these points. The overlay results show that brown points indicate ground, while non-brown points indicate non-ground. According to Aisyah (2017), to address the inaccuracies in automatic classification, a manual classification process is necessary. This process is called manual classification.

Inundation Mapping with HEC-RAS

Flood inundation modeling in watersheds using HEC-RAS has been conducted by researchers, including (et al., 2020; Irawan et al., 2021; Nagarajan et al., 2022;

Gunawan et al., 2023). In this study, the creation of a flood inundation map of the Ciujung River overflow involves two stages: river geometry creation and flood inundation simulation using HEC-RAS. The river geometry in this study is done using digitization techniques, with the DTM of the research area serving as the reference data. The process involves removing LiDAR points found in water bodies and converting the LiDAR data to DTM data. Creating river geometry and extracting Manning's roughness values for land cover is done using tools from the HEC-GeoRAS 10.3 application. Flood inundation simulation can then be performed using HEC-RAS 5.0.1. HEC-RAS is one of the most popular models that provides flood elevation or water surface elevation (WSE) dimensions for rivers, river flows, etc. This model solves the energy equation based on the Saint-Venant equations using an iterative procedure known as the standard step method (Kumar et al., 2017). According to Brunner (2016), the energy equation is written as follows (Cahyono & Hak, 2023):

$$Z_2 + Y_2 + \frac{a_2 V_2^2}{2g} = Z_1 + Y_1 + \frac{a_1 V_1^2}{2g} + h_e$$

Where:

Z_1, Z_2 = the elevation of the main channel inverts
Y_1, Y_2 = a depth of water at cross sections
V_1, V_2 = average velocities (total discharge/total flow area)
a_1, a_2 = velocity weighting coefficients
g = gravitational acceleration
h_e = energy head loss

RESULT AND DISCUSSION

Flood Inundation Simulation

The flood inundation simulation stage was conducted using steady flow simulation available in the HEC-RAS software. This process requires topographic slope data along the river channel and flow discharge data to be simulated. According to data from BBWS C3 Banten Province, the average topographic slope of the river used in this study is 0.0002, as the research area is located downstream. The flow discharge simulated in this study includes 1000 m^3/s, 1500 m^3/s, 2000 m^3/s, 2500 m^3/s, and 3000 m^3/s. These discharge values are based on upstream boundary conditions, with the highest recorded discharge at the Pamarayan Water Control Post (PDA) being 2600 m^3/s.

In the classification stage, the point cloud was divided into two classes: ground and non-ground. In Figure 3, brown points indicate the ground class, while gray points indicate the non-ground class. The classification results can be seen in Figure 4, which shows a cross-sectional view of a small part of the research area.

To ensure that the point cloud classification results are divided according to their respective classes, in Figure 4, the brown color representing the ground class depicts the contour lines of the surface area. Meanwhile, the gray color does not resemble the surface contour but rather resembles the shape of a roof, which is higher than the surface and thus falls into the non-ground class. Subsequently, a filtering process is performed to separate and retain only the points in the ground class, as seen in Figure 5. These ground class points will be used for the formation of the Digital Terrain Model (DTM).

The ground class point cloud is further processed to form a Digital Terrain Model (DTM). The DTM generated in this study is in GRID format. In Figure 6, the DTM formation results are displayed in grayscale, where darker shades indicate areas with lower values.

The results of the DTM at this stage involved adjusting with the Digital Elevation Model (DEM) data downloaded from the INA Geoportal. The adjustment was limited to assessing the conformity of topographic features and elevation value ranges between the DTM model and the downloaded DEM model. It was found that the modeling results matched the actual surface of the earth. Figure 7 shows the DTM display.

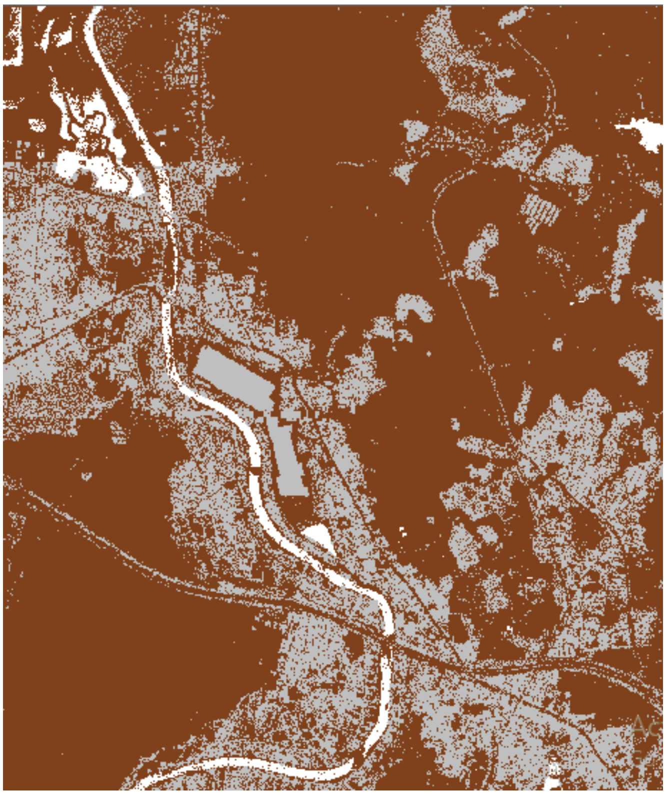

Figure 3. Point cloud classification results.

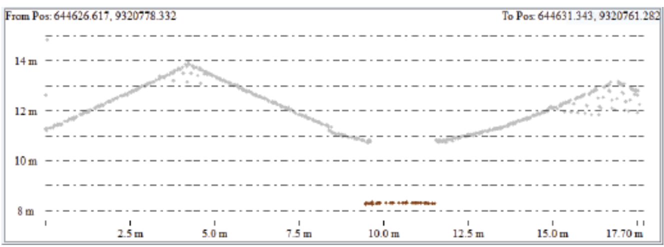

Figure 4. Cross-sectional view.

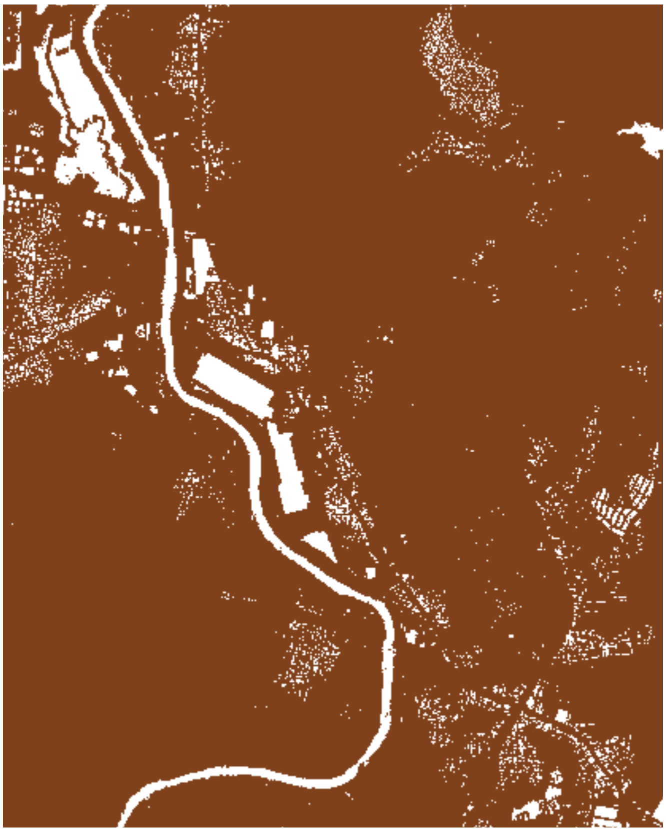

Figure 5. Ground class point cloud.

Figure 6. DTM in grid format.

After the DTM is formed for the research area, it is then used in the river geometry creation process. River geometry creation involves digitizing the main river channel, riverbanks, and cross-sectional profiles. This digitization process is carried out using HEC-RAS 5.0.7 software. Below, in Figure 8, you can see the digitization results and the formed river geometry.

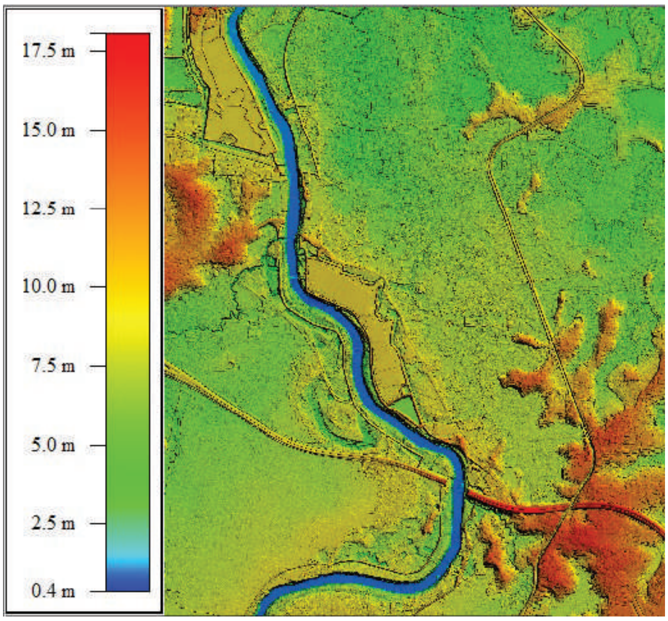

Figure 7. DTM in color display.

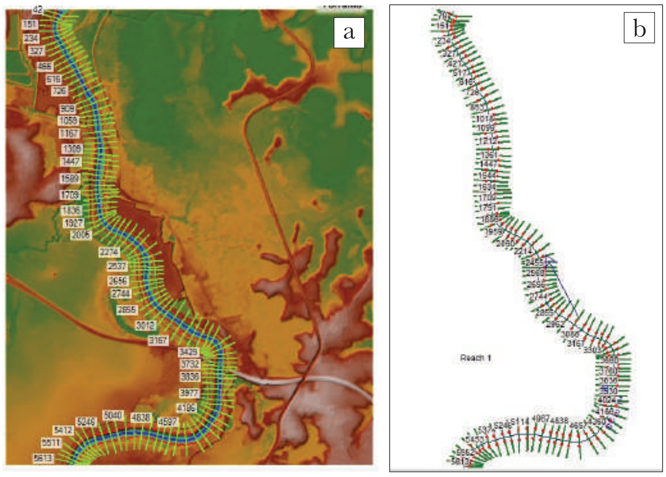

Figure 8. a) River cross-section digitization; b) River geometry.

The green lines in the image represent the cross-sectional profiles of the river, which display the cross-sectional profile of the DTM. These profiles enable the depiction of flood water levels along the cross-section. The river geometry serves as the basis for flood inundation simulation processes. During simulation, discharge data and the slope of the river's topography are used. This simulation is conducted using HEC-RAS 5.0.7 software. The simulation results produce flood depth, as shown in Figure 9, illustrating how high the water reaches at various points in the affected area.

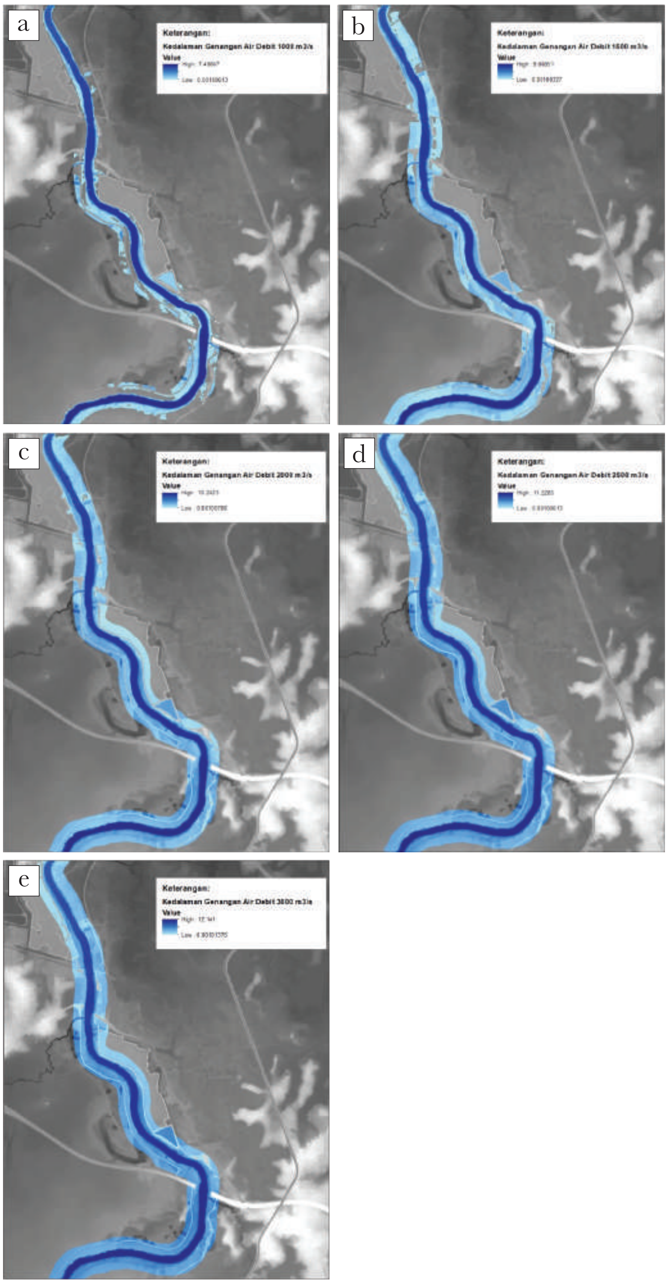

Figure 9. Flood elevation results discharge: (a) 1000 m³/s (b) 1500 m³/s (c) 2000 m³/s (d) 2500 m³/s (e) 3000 m³/s.

Analysis of Flood Depth

The results of the steady flow simulation using HEC-RAS software yielded flood depth profiles. During the simulation process, various discharge inputs were repeatedly used to determine the maximum capacity of the river cross-sections to accommodate water discharge. The findings indicated that the maximum discharge capacity held by the river at each cross-section was 775 m³/s. When the river discharge exceeded 1000 m³/s and beyond, it resulted in overflow beyond the river's boundaries, thus classified as flooding.

The flood depth results show varying water levels for each increase in discharge. At a discharge of 1000 m³/s, the water level ranged from 0.001 to 7.4 m, while at 1500 m³/s, it ranged from 0.001 to 9.0 m. At 2000 m³/s, the water level ranged from 0.001 to 10.2 m, at 2500 m³/s it ranged from 0.001 to 11.2 m, and at 3000 m³/s it ranged from 0.001 to 12.1 m. These results indicate an average increase in flood depth of 1 to 1.5 m for every 500 m³/s increase in discharge.

This trend is illustrated in Figure 10, which depicts the increase in water depth corresponding to each discharge level at one of the river cross-sections. The results highlight how increasing discharge affects the water level profiles along the river, with higher discharges resulting in greater depths.

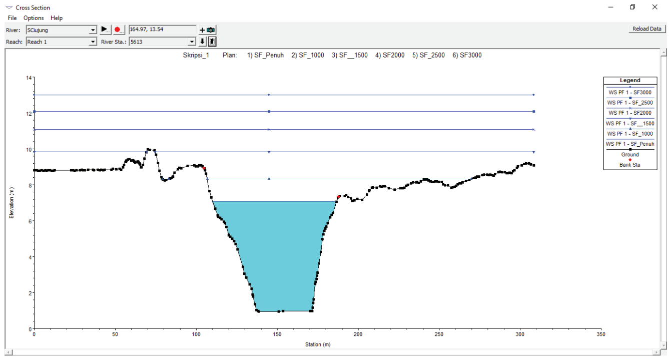

Figure 10. Cross-sectional profile of the river.

Flood inundation mapping shows the areas along the riverbanks that are inundated and prone to flooding. The results of flood inundation mapping also indicate variations in the flooded area along the riverbanks at intervals of 100 m. The flooded area at each discharge can be seen in Table 1.

Figure 1. Flooded area of riverbanks.

Discharge (m³/s)	Flooded Area of Riverbanks (Ha)
1000	32,37
1500	79,47
2000	97,48
2500	105,86
3000	109,06

In the table, you can see that the flooded area along the riverbanks increases with the rising river discharge. This is because higher river discharge means more water flowing into the river. From the results of the steady flow simulation in the research area, a discharge of 775 m³/s was obtained when the flooding reached the river's threshold limit. As the discharge increased to 1000 m³/s and beyond, several areas were identified as potentially prone to flooding, necessitating mitigation efforts for residents living in the Ciujung River buffer zone.

Validation of Simulation Results Based on flood inundation simulation using HEC-RAS, validation was conducted to determine if the flood simulation results were representative. In this study, validation involved simulating flood inundation from the overflow of the Ciujung River based on the discharge data during the flood event on December 7, 2020, which was 1389.50 m^3/s and used as a sample. Subsequently, validation was performed through interview methods, where data was collected by directly asking respondents using questionnaires. The interview questions focused on the flood event on December 7, 2020, as detailed in the appendix. Following this, a comparison was made between the flood inundation simulation results during the event and the field interview results. To determine the percentage of sample validation results from field interviews, the following formula was used:

$$\frac{\text{Number of sample points}}{\text{Total number of sample points}} \text{ X } 100\%$$

The sample points obtained from the interviews totaled 20 points, divided into 12 points affected by flooding and 8 points unaffected by flooding in the flood inundation simulation results. Table 2 shows the field validation results of flood inundation, indicating an 80% validation rate with 16 sample points considered valid and 20% with 4 points considered invalid. Therefore, the validity of the flood inundation simulation results using HEC-RAS software can be considered sufficiently valid based on respondent feedback.

Figure 2. Field validation results.

Analysis	Field Sample Points Affected by Flood	Total Points	Percentage (%)	Valid Points
Results	Floods	12	60	9
	Not Floods	8	40	7
Validation	Valid	16	80	16
	Not Valid	4	20	4
	Total	20	100	20

CONCLUSION

The use of DTM derived from LiDAR data significantly aids in river geometry creation, providing a high-resolution of 1 x 1 meter that facilitates clear visualization and interpretation of river geometries. The mapping results of flood inundation at various discharge levels demonstrate the areas susceptible to flood risks along the riverbanks. This allows for appropriate measures to be taken in flood disaster mitigation. The validation test results from 12 flood sample points in the field showed a 60% validity rate based on respondent feedback. The flood-prone area along the Ciujung River's banks expands with increasing discharge, reaching its largest extent at 3000 m^3/s, covering 109.06 hectares.

ACKNOWLEDGEMENTS

The author extends heartfelt thanks to the Government of Banten Province, BBWS C3 Banten Province for their support in providing data, and the US Army Corps of Engineers Hydrologic Engineering Center for the open-source HEC-RAS application that facilitated the analysis.

CONFLICT OF INTEREST

The author declares no conflict of interest in the research and preparation of this article.

REFERENCES

Ariyora, Y. K. S., Budisusanto, Y., & Prasasti, I. (2015). Pemanfaatan Data Penginderaan Jauh Dan Sig Untuk Analisa Banjir (Studi Kasus : Banjir Provinsi Dki Jakarta). *Geoid, 10(2), 137*. https://doi.org/10.12962/j24423998.v10i2.805

Asriyah, N., Harto, A. B., & Wikantika, K. (2017). *Pemanfaatan Teknologi Light Detection and Ranging (LIDAR) Dalam Pemodelan Banjir Akibat Luapan Air Sungai*. Institut Teknologi Bandung.

Cahyono, A. B., & Hak, A. B. (2023). Flood Inundation Simulation Using HEC-GeoRAS with Hydro-Enforced-DTM LiDAR Data. *IOP Conference Series: Earth and Environmental Science, 1127(1)*. https://doi.org/10.1088/1755-1315/1127/1/012049

Chalid, A., Suhirna, U., & Siregar, C. A. (2022). Analisis Pengaruh Erosi Lahan Pada Daerah Aliran Sungai Ciujung Kabupaten Lebak. *Jurnal Talenta Sipil, 5(1)*, 144. https://doi.org/10.33087/talentasipil.v5i1.107

Gunawan, G., Peri, B., Misliniyati, R., Trie Saputra, I. K., Patrianusa, I., & Aqilah, H. (2023). Flood Inundation Modeling for the Lower Bengkulu Sub-Watershed of Bengkulu Province Using the Hec-Ras 5.0.7 Program Based on Ras Mapper and Arc-Gis 10.8. *Media Komunikasi Teknik Sipil, 29(1)*, 84–92. https://doi.org/10.14710/mkts.v29i1.53915

Irawan, T., Haza, Z. F., & Widaryanto, L. H. (2021). Analisis Genangan Banjir Menggunakan Sistem Aplikasi Hec-Ras 5.0.7 (Studi Kasus Sub-DAS Sungai Dengkeng). *Teknik Sipil, 6(1), 24–33*. https://jurnal.ustjogja.ac.id/index.php/renovasi/article/view/10131

Istiadi, Y., & Priatna, D. (2021). Analysis of the determinants and typology of hydrometeorological disaster in Sukajaya Subdistrict, Bogor Regency, West Java, Indonesia. *Indonesian Journal of Applied Environmental Studies, 2(1): 41-46*. DOI: 10.33751/injast.v2i1.3113

Kumar, N., Lal, D., Sherring, A., & Issac, R. K. (2017). Applicability of HEC-RAS & GFMS tool for 1D water surface elevation/flood modeling of the river: a Case Study of River Yamuna at Allahabad (Sangam), India. *Modeling Earth Systems and Environment, 3(4), 1463–1475*. https://doi.org/10.1007/s40808-017-0390-0

Mahfudz, M., Riadi, B., Nurtyaman, R., & Utomo, P. P. (2024). Satellite Image Analysis Approach for Identifying Flood Impacts in DKI Jakarta. *Engineering and Technology Journal, 09(04), 3763–3771*. https://doi.org/10.47191/etj/v9i04.14

Mahfudz, M., Riadi, B., & Rifaldi, I. (2022). Pemetaan Area Potensi Banjir Berdasarkan Topographic Wetness Index (TWI) di Kecamatan Cigudeg Kabupaten Bogor. *Jurnal Ilmiah Geomatika, 28(1), 13–19*.

Naitkakin, E., Rachman, L. M., & Hidayat, Y. (2023). Daya Dukung Biofisik Sub Daerah Aliran Sungai Ciujung Hulu, Provinsi Banten. *Jurnal Ecosolum, 12(2), 192–204*. https://doi.org/10.20956/ecosolum.v12i2.32166

Nucifera, F., & Putro, S. T. (2018). Deteksi Kerawanan Banjir Genangan Menggunakan Topographic Wetness Index (TWI). *Media Komunikasi Geografi, 18(2), 107*. https://doi.org/10.23887/mkg.v18i2.12088

Yulihastin, E. (2011). Anomali Curah Hujan 2010 di Benua Maritim Indonesia Berdasarkan Satelit TRMM Terkait. *Prosiding Simposium Nasional Inovasi Pembelajaran Dan Sains, June, 0–5*.

InJAST
Volume 5, Number 2, October 2024
Pages: 65-83
P - ISSN: 2722 - 0133
E - ISSN: 2722 - 0141
DOI: 10.33751/injast.v5i2.10690

GIS-based analysis of water quality risk factors and CKDu prevalence in Northern Yobe State, Nigeria

MODIBBO BABAGANA-KYARI*, **NURA ALHAJI YARO, KABIRU M. YAKASAI**

Department of Environmental Health and Safety, School of Health Sciences, Maryam Abacha American University of Niger, Maradi

*Corresponding author: *modibbobgk@gmail.com*

Submitted 5 September 2024; Accepted 4 November 2024

ABSTRACT

Chronic Kidney Disease (CKDu) presents a major public health challenge in Northern Yobe State, Nigeria, particularly in the Bade community, where water quality is overly suspected to influence its prevalence. This study employs a Geographic Information Systems (GIS)-based framework to analyze the spatial distribution of CKD in relation to water quality parameters. Advanced spatial analysis techniques, including hexagonal tessellation and Moran's I for spatial autocorrelation, were utilized alongside community-based surveys conducted using Kobotoolbox and Qfield applications to map CKD hotspots. The Moran's I Index of 0.1046, with a z-score of 4.9546 and a p-value of 0.000001, indicates significant clustering of CKD cases rather than random distribution across the study area. Water samples from 30 water facilities, with 10 from each classified hotspot, were analyzed for nephrotoxic heavy metals, ionic concentrations, and hardness using an Atomic Absorption Spectrometer (Model 210V-GP). The spatial distribution of these parameters was modeled using Inverse Distance Weighting (IDW) interpolation in ArcGIS Pro 3.4. Descriptive statistics, hazard index calculations, and Water Quality Index (WQI) assessments were conducted, with box plots facilitating comparative analysis across High, Medium, and Low disease areas. ANOVA and Tukey's HSD post-hoc tests were performed to compare specific water parameters between the disease hotspots and water facilities. The results revealed elevated concentrations of nephrotoxic heavy metals in high-disease hotspots, with maximum values observed for Arsenic (0.21 mg/L), Cadmium (0.30 mg/L), Lead (0.23 mg/L), Chromium (0.50 mg/L), and Fluoride (55 mg/L). Additionally, Nitrite and Nitrate levels exhibited high Hazard Quotients, all surpassing WHO guidelines for safe drinking water. These findings underscore the potential health risks posed by these contaminants in affected areas. Results demonstrate a significant link between the prolonged use of handpumps water and high prevalence of chronic kidney disease incidence (CKD) among affected households. Additionally, the study identified strong spatial correlations between CKD incidence and high concentrations of nephrotoxic heavy metals in water from handpumps, providing critical insights for targeted public health interventions and guiding future research efforts.

ABSTRAK

Penyakit Ginjal Kronis (CKDu) menghadirkan tantangan kesehatan masyarakat yang besar di Negara Bagian Yobe Utara, Nigeria, khususnya di komunitas Bade, di mana kualitas air diduga sangat mempengaruhi prevalensinya. Penelitian ini menggunakan kerangka kerja berbasis Sistem Informasi Geografis (GIS) untuk menganalisis distribusi spasial CKD dalam kaitannya dengan parameter kualitas air. Teknik analisis spasial tingkat lanjut, termasuk tesselasi heksagonal dan Moran's I untuk autokorelasi spasial, digunakan bersamaan dengan survei berbasis komunitas yang dilakukan menggunakan aplikasi Kobotoolbox dan Qfield untuk memetakan hotspot CKD. Indeks Moran's I sebesar 0,1046, dengan skor z sebesar 4,9546 dan nilai p sebesar 0,000001, menunjukkan pengelompokan kasus CKD yang signifikan dibandingkan distribusi acak di seluruh wilayah penelitian. Sampel air dari 30 fasilitas air, dengan 10 dari masing-masing hotspot yang diklasifikasikan, dianalisis logam berat nefrotoksik, konsentrasi ionik, dan kekerasan menggunakan Spektrometer Serapan Atom (Model 210V-GP). Distribusi spasial parameter ini dimodelkan menggunakan interpolasi Inverse Distance Weighting (IDW) di ArcGIS Pro 3.4. Statistik deskriptif, penghitungan indeks bahaya, dan penilaian Indeks Kualitas Air (WQI) dilakukan, dengan plot kotak yang memfasilitasi analisis komparatif di wilayah dengan penyakit Tinggi, Sedang, dan Rendah. Uji post-hoc ANOVA dan HSD Tukey dilakukan untuk membandingkan parameter air spesifik antara titik panas penyakit dan fasilitas air. Hasilnya menunjukkan peningkatan konsentrasi logam berat nefrotoksik di titik rawan penyakit, dengan nilai maksimum yang diamati untuk Arsenik (0,21 mg/L), Kadmium (0,30 mg/L), Timbal (0,23 mg/L), Kromium (0,50 mg/L).), dan Fluorida (55 mg/L). Selain itu, tingkat Nitrit dan Nitrat menunjukkan Tingkat Bahaya yang tinggi, semuanya melampaui pedoman WHO untuk air minum yang aman. Temuan ini menggarisbawahi potensi risiko kesehatan yang ditimbulkan oleh kontaminan ini di daerah yang terkena dampak. Hasilnya menunjukkan adanya hubungan yang signifikan antara penggunaan air pompa tangan dalam waktu lama dan tingginya prevalensi kejadian penyakit ginjal kronis (CKD) di antara rumah tangga yang terkena dampak. Selain itu, penelitian ini mengidentifikasi korelasi spasial yang kuat antara kejadian CKD dan tingginya konsentrasi logam berat nefrotoksik dalam air dari pompa tangan, memberikan wawasan penting untuk intervensi kesehatan masyarakat yang ditargetkan dan memandu upaya penelitian di masa depan.

Keywords: *CKDu, CKD Hotspots, Disease mapping, Hazard Quotient, Voronoi tessellation, GIS, spatial Analysis, Nephrotoxicity*

INTRODUCTION

Chronic Kidney Disease of uncertain etiology (CKDu) has been a growing concern in various parts of the world, particularly in agricultural communities (Weaver, Fadrowski, & Jaar, 2015; Priyadarshani et al., 2023). The disease is characterized by its occurrence in individuals without the typical risk factors associated with Chronic Kidney Disease (CKD), such as diabetes or hypertension (Lunyera et al., 2016; Gifford et al., 2017). Despite this increase, the specific environmental and lifestyle-related risk factors contributing to CKDu remain poorly understood in many of the areas where the disease is so prevalent (Wesseling et al., 2013; Weaver et al., 2015). In regions like Northern Yobe, Nigeria, CKDu has become a significant public health issue, with a rising number of cases reported over the past decade based on hospital records observation (Sulaiman et al., 2019; Goni et al., 2024).

The geographical and environmental context of Northern Yobe State, characterized by its agricultural economy and reliance on groundwater, suggests a potential link between environmental exposures and CKDu. Preliminary studies in the CKD hotspots of Yobe region implicated groundwater and food resources grown in the area (Waziri et al., 2017; Gashua et al., 2018; Oyekanni et al., 2018; Ahmed et al., 2018) as heavy metals were found exceeded benchmark standards. However, the recent study of conducted by Aminu et al., (2022) have observed that heavy metals were found in biomedical samples of the patients diagnosed with CKD in the area. Similarly, Yuguda et al., (2022) study reported high concentrations of Cadmium, Lead and mercury exceeding permissible limits at all the sites where samples were collected.

Several studies have implicated water quality, particularly contamination by heavy metals, agrochemicals, and other pollutants, as a potential contributor to CKDu in similar settings (Wanigasuriya, 2012; Jayatilake et al., 2013). However, the link between these environmental risk factors, particularly water and the prevalence of CKDu in Northern Yobe State has not been systematically explored in spatial context despite the number of different study attempts.

Remarkably, Geographical Information Systems (GIS) provides a powerful tool for exploring the spatial dimensions of environmental health problems. GIS allows for the integration of various data sources (Saputro et al., 2023; Priatna & Monk, 2023), including environmental, health, and demographic data, to identify spatial patterns and relationships that might not be apparently seen through traditional epidemiological methods (Huang et al., 2021). In recent time, GIS has been very used to explore the spatial distribution of diseases and their potential associated environmental factors, providing deep insights that is not known (Oviasu, 2012; Sanati, 2015; Senanayake, 2016).

In the context of CKDu, GIS has the potential to uncover spatial correlations between disease prevalence and environmental factors such as water quality. Greatly mapping CKDu incidences and overlaying these with environmental data, one can identify potential hotspots and explore the geographic distribution of risk factors and their concentration as well. This approach has been successfully applied in other regions affected by CKDu, where it has helped to identify areas of high disease burden and potential environmental exposures (Rodriguez et al., 2013; Jayasumana et al., 2015; Vlahos et al., 2021).

The novelty of this study lies in its application of a community-centric approach, utilizing GIS to identify and map CKDu incidences at the household level in Northern Yobe State. Unlike traditional hospital-based studies, which may miss cases in remote or underserved areas, this approach involves direct engagement with communities to gather data on CKDu prevalence and potential environmental risk factors. Through integrating community surveys with GIS-based spatial analysis, the study seeks to offer a more thorough understanding of water risk factors and chronic kidney disease of unknown etiology (CKDu) prevalence in the region. This approach addresses the contentious hypothesis that has yet to be conclusively proven. This study is significant as it represents one of the first attempts to systematically investigate the relationship between water quality and CKDu in Northern Yobe State using a GIS-based approach.

METHODS

Study Area

The chosen study region encompasses the entirety of Northern Yobe State, with a specific focus on Bade Local Government Area. Bade Local Government Area is situated in the northeastern region of Nigeria, characterized by its geographical coordinates at latitude 12° 52' 25.12 " N and longitude 11° 2' 49.94" E respectively (Figure 1). This area shares its borders with Nguru Local Government Area to the north, as well as Bursari and Jakusko Local Government Areas to the east and west respectively. Notably, Bade LGA emerges as a significant focal point for this research due to its higher prevalence of Chronic Kidney Disease of Unknown etiology (CKDu). Due to the heightened prevalence of CKDu makes Bade LGA, particularly Gashua town, a key area for the research. Bade Local Government Area, holds a strategic position at the convergence of the Hadeija, and Jama'are rivers, which combine to form the Yobe River. This river system eventually joins the Kumadugu-Gana River at Damasak and flows into Lake Chad. This extensive water network serves as a vital water source for domestic and agricultural needs, supporting fisheries and sustenance for numerous local communities.

The region's soil fertility is enhanced by its loamy-clay and silty soils, fostering paddy rice cultivation that plays a pivotal role in the livelihoods of the local population. Traditionally, the area is primarily agrarian, with farming and fishing being the dominant occupations due to the abundance of accessible open and ground waters, often found at shallow depths in floodplains. A noteworthy aspect of this agricultural landscape is the practice of paddy rice cultivation, which has been a central occupation for the community for nearly four decades. This enduring commitment to paddy rice cultivation underscores its significance in the lives of the locals. The long-standing tradition of rice farming highlights the area's connection to its agricultural heritage and signifies the pivotal role that agriculture plays in the socio-economic fabric of the region. The area maintains an average elevation of approximately 370 meters above sea level. Its geological composition aligns with the broader geological features of the Lake Chad region. The geological makeup of the region can be broadly categorized into three main groups: a) Crystalline Basement Complex of Pre-Cambrian origin, b) sedimentary Chad Formation dating to the Tertiary and Quaternary periods, and c) Quaternary-age alluvium and aeolian sands, as reported by Alkali (1995).

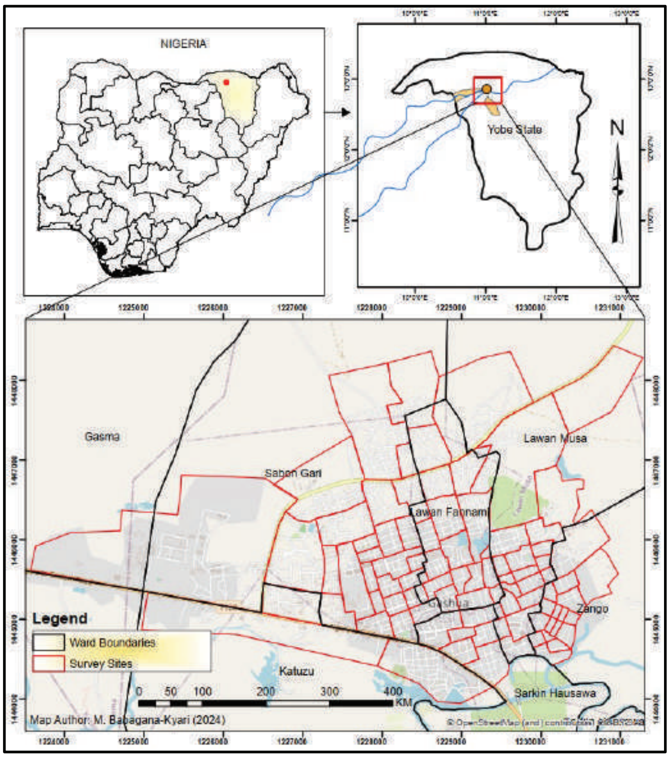

Figure 1. Study area map in northern Yobe State, Nigeria.

The local climate of the area adheres to the tropical pattern prevalent in northern Nigeria, characterized by distinct wet and dry seasons. Jajere et al., (2018) have identified three primary seasons within the study area: The hot-dry season spanning April to June, and the warm-moist season set in July to September, while the cold-dry season prevailing from December to February. As for Gashua's average temperature, it registers at 43 degrees Celsius.

Study Design

This study employs a descriptive, hotspot-based cross-sectional design to collect data on CKD prevalence directly from the community through household surveys of affected individuals. The primary aim is to identify CKD hotspots within Gashua main town, targeting areas with elevated incidences of the disease, encompassing both morbidity and mortality cases. Gashua town was purposively selected due to the high endemicity of CKD (Sulaiman et al., 2019). This approach allows for a comprehensive analysis of the relationship between groundwater quality, various confounding factors, and CKD occurrences (Figure 2).

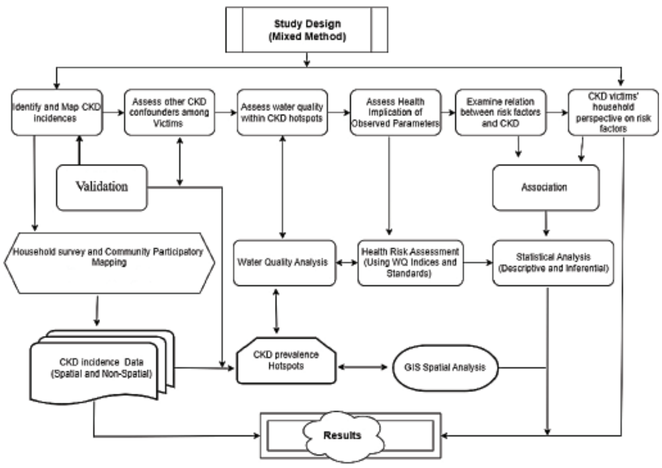

Figure 2. Methodology flow chart.

The choice of this design is particularly significant given the lack of geocoded hospital records, which are often crucial for accurate spatial analysis of disease prevalence (Oliver et al., 2005). While geocoded hospital data can offer valuable insights into disease distribution and hotspots, its absence in this context necessitates alternative methods for capturing localized disease incidences (Luby et al., 2015; Xie et al., 2017). Previous studies have demonstrated that community-based surveys and participatory mapping can effectively substitute for hospital records in areas where such data are unavailable (Fornace et al., 2018). Thus, through adopting a community-centric approach, this study underscores the importance of local factors and perspectives in understanding disease patterns in the region.

Data Collection

Incidence survey techniques

A community-based survey was employed using Kobotoolbox for survey design and deployment, and QField application for in-field data verification, GPS mapping. Community engagement included participatory and house-to-house surveys to identify households with confirmed chronic kidney disease (CKD) cases (mortality and morbidity) and collect detailed information on household water sources and usage patterns. Only cases confirmed through health facilities were included in the survey. During the survey, medical records (documents) of the individuals were requested for verification. Six field workers were recruited and trained specifically for the house-to-house survey, which was carried out for a period of 28 days in the study area after which the survey was halted.

Additionally, a reconnaissance was conducted to pretest the instrument in the Lawan Fannami ward. The electronic survey instrument captured both location and key sociodemographic variable of CKD patients/victims and household water usage pattern. Prior to survey, ethical approval was obtained first from Yobe State Ministry of Health's Research ethics committee. Moreover, informed consent was obtained from each study participant, with the consent process outlined at the beginning of the questionnaire which clearly explain the nature and purpose of the study. Participants were required to consent with either 'Yes' or 'No' before participating in the exercise.

A snowball sampling method was employed, with the assistance of neighborhood heads (Community Leaders), to identify households with CKD cases. The Enumeration Area of DLI 11.3 was utilized for the incidence survey to prevent duplication in data collection, as each fieldworker was assigned a specific spatial unit. Information was primarily provided by household heads and patients' attendants in households as majority of the victims are deceased while some are medically not fit to actively participate in the survey. The survey identified 441 medically confirmed cases across 430 households, accounting for instances where multiple cases were present in some households. To prevent duplication, field workers were assigned with coded Enumeration Areas (EAs) based on the 2022 Yobe State Geographic Information Service property enumeration area shapefile for Disbursement link indicator (DLI 11.3) project as depicted in Figure 1.

Water sample collection techniques

Water samples were systematically collected within the observed CKD hotspots and subjected to laboratory analysis for nephrotoxic heavy metals (Arsenic, Cadmium, Chromium, Mercury, Lead), key ions (Fluoride, Sodium, Nitrite, Nitrate, Phosphate), and water hardness indicators (Magnesium and Calcium). Additional parameters, including pH and turbidity, were also measured to provide a comprehensive assessment of water quality.

A hotspot-based stratified random sampling method was employed to ensure representative sampling across the three distinct CKD hotspot levels high, medium, and low incidence areas. From each hotspot category, 10 water facilities were randomly selected, resulting in a total of 30 water facilities being sampled. This approach ensured a balanced distribution of samples across different levels of disease prevalence, capturing variability in water quality across the identified areas. The sampling included a range of water facilities, such as hand pumps, deep boreholes, and tap stands, encompassing both public and private sources, except for newly constructed facilities.

To ensure the integrity and reliability of the samples, standard procedures were rigorously followed during collection. A total of 90 water samples were collected in triplicate from the 30 selected water points using clean plastic bottles. Samples were obtained during periods of active use, specifically after the facilities had been in continuous operation for over 5 hours. The samples were carefully tagged and promptly transported to Yobe State University Chemistry Research Laboratory, where they were analyzed under controlled conditions to maintain their integrity.

Geographic Information System (GIS) analysis techniques

The study employed a GIS-based methodology to explore the geographic distribution of CKD cases in relation to water quality parameters. To assess spatial autocorrelation, Moran's I was utilized, a statistical technique that identifies clustering or dispersion within spatial data, enabling the examination of disease prevalence patterns. To ensure uniform sampling, a hexagonal tessellation covering a total area of 20,000 square meters was applied across the study region. Each hexagon served as a sampling unit for surveying CKD prevalence, enabling a spatial join between CKD incidence data and the tessellated polygons. This method facilitated the quantification of disease counts per unit area.

Through the GIS analysis, three distinct hotspots were identified based on CKD prevalence and classified into high, medium, and low prevalence areas. A choropleth map was subsequently generated to visually represent the spatial distribution of CKD prevalence, using a red color gradient to differentiate the intensity of the disease across the study area. For the selected water points, Voronoi tessellation was employed to define the presumed service areas of the water facilities (see, Figure 11). This tessellation allowed for estimating the regions from which nearby residents are likely to collect water for domestic use.

Water quality analysis

Water samples collected from the 30 water points across the three identified CKD hotspots were analyzed to determine the concentration of nephrotoxic heavy metals, key ions, and water hardness indicators. An Atomic Absorption Spectrometer (Model 210V-GP) was employed for the analysis of these samples. The data obtained from these analyses were mapped and compared with CKD prevalence so as to identify potential environmental risk factors in water contributing to the disease.

Spatial modeling and data analysis

Spatial modeling and data analysis were conducted using ArcGIS Pro 3.4, where Inverse Distance Weighting (IDW) interpolation with a geometric interval classifier was used to model the spatial distribution of the water quality parameters. Descriptive statistics, including minimum, maximum, and mean values of the water samples for each hotspot, were calculated and compared against benchmark standards set by the World Health Organization (WHO) and the U.S. Environmental Protection Agency (EPA). ANOVA, Tukey's HSD post-hoc tests were conducted to identify specific differences between pairs of hotspots particularly high and low hotspots. For the health risk assessment, Hazard Quotient (HQ) was calculated to evaluate the potential risk posed by contaminants. The Hazard Quotient (HQ) for each heavy metal and ion was calculated using the following formula developed by United State Environmental Protection agency (EPA):

$$HQ = \frac{ED}{RfD}$$

Where:

ED = Exposure Dose (Contaminant Concentration values)

RfD = Reference Dose (the safe contaminant exposure limit provided by WHO or EPA (see, Appendix 1 & 2)

HQ<1 : The exposure is considered to be within the safe limit, and adverse health effects are unlikely

HQ≥1 : The exposure exceeds the safe limit, indicating a potential health risk. The higher the HQ value, the greater the risk of adverse health effects.

Using the formula, the Hazard Quotient (HQ) of each contaminant was computed. The average HQ for each contaminant was then calculated to obtain the overall average HQ for each of hotspot using the formula:

$$\text{Average conc. for Hotspot} = \frac{\sum \text{Concentration Values}}{\text{Number of Samples}}$$

These average concentrations of each contaminant within each hotspot were used to compute the HQ, facilitating a comparative analysis through chart depicted in Figure 15. Additionally, the Water Quality Index (WQI) was computed to provide an overall assessment of water quality across the hotspots. A comparative analysis of the observed water quality parameters was performed using box plots, while the water usage characteristics and duration of residency of affected households were examined through the use of heat map. This integrated analysis provided deeper insights into potential correlations between water quality and CKD prevalence in the studied community.

RESULTS

This section presents the study's findings, with a focus on the fundamental characteristics of households impacted by chronic kidney disease (CKD) and the individuals residing within them. Key variables highlighted include the geographical location of the affected households and the duration of stay of the CKD victims within these households.

Victims' Household Characteristics

Figure 3 illustrates the distribution of responses to the consent question posed during the survey. The question was: "Consent for participation: If you are willing to participate in this survey, please respond 'Yes.' If you are not willing to participate, please respond 'No.' You are free to answer either way without any penalty".

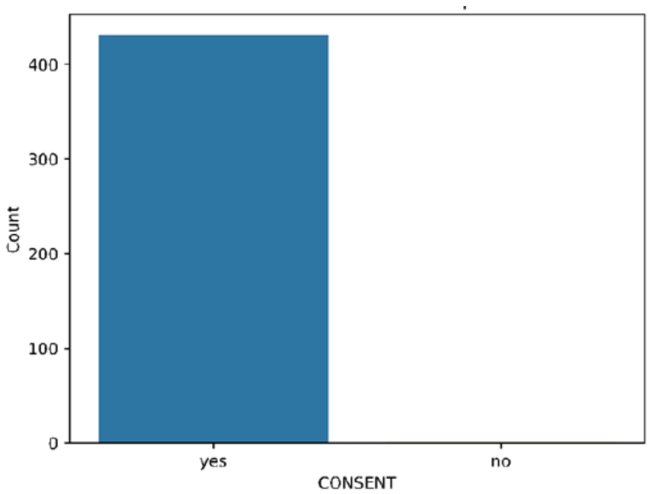

Figure 3. Distribution of study consent responses.

The 100% "Yes" responses indicate unanimous willingness among the respondents to participate in the CKD survey. Specifically, 431 out of 430 respondents expressed their consent by answering "Yes," with only one individual declining to participate. This demonstrates a high level of engagement and willingness to contribute to the study.

CKD Incidence Distribution in Household

The distribution of CKD incidence per household is illustrated to show how widespread the disease is within the study area. Table 1 presents the distribution of CKD incidences from the surveyed households. In the study area, 92.6% of households have one incidence of CKD, 2.46% have two incidences, and 4.7% have no incidences of CKD.

The results indicate that CKD is quite prevalent in the study area, with most households having at least one affected member. Specifically, 96.3% of households had only one CKD victim, while 2.46% had multiple cases. This suggests a need for targeted interventions for single-case households, while the presence of multiple cases may point to potential genetic or environmental factors.

Table 1. Number of CKD incidence in household in the study area.

Options	Frequency	Percentage (%)
1 incidence	414	92.6
2 incidences	16	2.46
None	11	4.7
Total	**441**	**100.0**

Source: Researchers' Fieldwork (2024)

Medical Confirmation of Household CKD Incidence

This section examines the responses to the questionnaire item regarding whether the household CKD incidence is medically confirmed. This information is critical for assessing the reliability of reported CKD cases and evaluating the potential for underreporting. Responses are categorized as "Yes" (medically confirmed) or "No" (not medically confirmed) to clarify the verification status of CKD cases within households (Table 2).

Table 2. Medical confirmation status of the incidence in household.

	Frequency	Percentage (%)
Yes	433	98.1
No	8	1.8
Total	**441**	**100**

Source: Researchers' Fieldwork (2024)

The result indicates that out of 433 CKD cases surveyed from 430 households, 98.1% (425 cases) were medically confirmed, while only 1.8% (8 cases) were not. This high percentage of confirmed cases indicates that most individuals had their CKD diagnosis validated by healthcare facilities, with physicians confirming the condition in most instances. The high level of medical verification is further supported by the fact that many households provided medical report documents to the research assistants during the survey

Respondent Status in Household

This section offers insight into the membership status of respondents within the household, with Figure 4 providing a visual breakdown of respondent statuses.

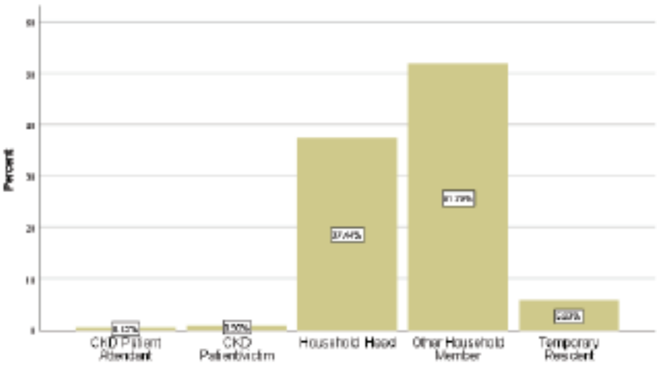

Figure 4. Household membership status of household respondents.

Notably, 37.44% of survey participants were household heads, while 51% were other household members. CKD patients comprised only 0.90% of respondents, suggesting a low representation likely due to mortality or morbidity. Nonetheless, household heads are considered reliable sources for information on household CKD incidence due to their comprehensive understanding of household affairs.

Age Group of the Respondent in Household

This section presents the age group distribution of respondents from households affected by the rampant incidence of chronic kidney disease (CKD). Figure 5 illustrates this distribution. It is noteworthy that the majority of the respondents fall within the 35-44 years age group, followed closely by those in the 25-34 years age group. The next largest group is the 45-54 years age group.

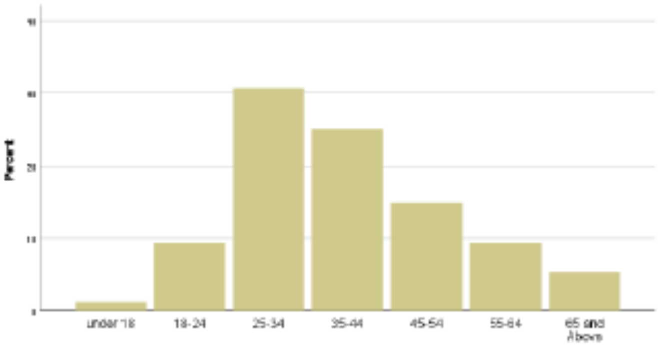

Figure 5. Age group distribution of the respondent.

Understanding the age distribution of respondents is crucial for assessing the quality of the information collected in the context of the rampant CKD incidence survey. Notably, respondents under the age of 18 years constituted less than 5% of the respondent, indicating a low representation of this age group.

Educational Level of Respondent

The part displays the various categories of the educational levels of respondents from surveyed household. Table 3 illustrate the educational profile of respondents who reported the incidence of household CKD. The data shows a variety of educational levels ranging from 'High Secondary School' to 'Postgraduate degree'. The majority of respondents have a high secondary school education (51.8%, 231). This is followed by those with informal education (16.8%, 72) and some college or bachelor's degree (15.7%, 68). Lesser percentages are noted in primary school education (6.5%, 28), Islamic education (4.4%, 19), and postgraduate degrees (2.8%, 12), highlighting a diverse educational background among the surveyed individuals. The total count of respondents is 430, accounting for 100% of the data presented in the table.

Table 3. Educational level of the respondent.

Category	Frequency	Percentage (%)
High Secondary School	231	51.8
Informal School	75	16.8
Some college / Bachelor's degree	70	15.7
Primary School	29	6.5
Islamic education	18	4.0
Postgraduate degree	7	1.6
Total	**430**	**100.0**

Source: Researchers' Fieldwork (2023)

The above insights indicate that a significant percentage of respondents were literate, suggesting they fully understood the questionnaire used. Relatively, with 51.8% having completed high secondary school and 15.7% having some college or a bachelor's degree, the majority have a solid educational foundation. Additionally, the presence of respondents with postgraduate degrees (2.8%) underscores their literacy and comprehension levels.

Gender of the Respondent

The gender of the respondent also provides valuable insights into the study, indicating who predominantly participated in the survey. The Table 4. illustrate the distribution of the gender of the respondents. From the data it can be seen that 81.6% were male while 14.8% were female. This because the majority of the persons participated in the study were house head (HH) who were Males.

Table 4. Gender distribution of the household respondents.

Category	Frequency	Percentage (%)
Male	364	81.6
Female	66	14.8
Total	**430**	**100.0**

Source: Researchers' Fieldwork (2023)

The gender distribution of respondents in the CKD incidence survey provides significant context for understanding the demographics of those reporting household CKD incidences. Figure 6 shows that a significant number of residents have lived in their current households for 6 to 10 years, as indicated by the highest percentage (38.57%).

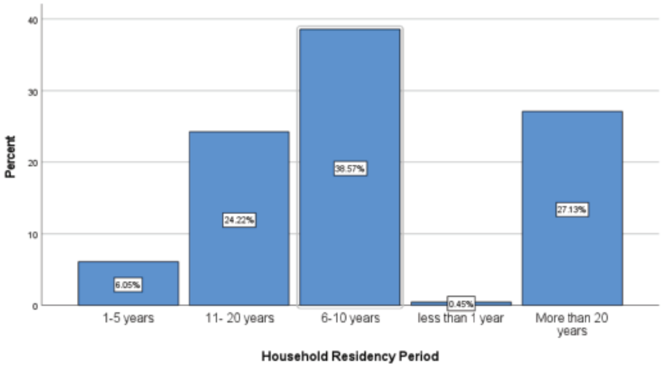

Figure 6. CKD victims' Household period of residency.

Additionally, a substantial percentage of households have been residing in the area for more than 20 years (27.13%). Conversely, households that have spent 1-5 years (6.05%) and less than 1 year (0.45%) in their current residences have lower percentages. This deep insight clearly highlights the importance of considering residency duration when assessing CKD risk. The relationship between the length of residency and CKD risk can be analyzed further to understand the impact of environmental factors on the development of the disease.

Spatial Prevalence of CKD

This section examines the spatial distribution of CKD incidences within the study area through the application of Geographic Information Systems (GIS). It includes a detailed map illustrating the hotspots of CKD occurrences in Northern Yobe State and evaluates the hypothesis concerning the spatial distribution patterns of CKD incidences using spatial statistical analysis. Figure 7 presents map illustrating the distribution pattern of CKD incidence within the study area. The point features on the map represent the locations of households where CKD victims reside. Global Moran's I index was employed to analyze the spatial patterns of CKD incidence within the study area. Moran's I is a measure of spatial autocorrelation, which determines whether the distribution pattern of spatial object is clustered, dispersed, or random.

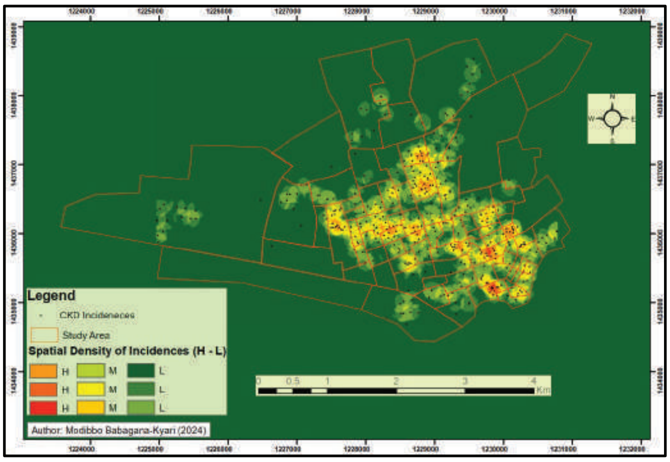

Figure 7. Map display of CKD hotspots in northern Yobe State.

The map uses a color gradient to represent the density of CKD incidences, ranging from green (indicating low density) to red (indicating high density). The most intense hotspots, represented by red, are predominantly located in the central part of the study area, indicating a significantly higher concentration of CKD incidences. Surrounding these high-density zones are areas of medium density (yellow), suggesting a moderate level of CKD incidences, while the green regions, denoting low-density CKD incidence, are primarily situated on the periphery of the map

Spatial autocorrelation statistics

Figure 8 below illustrates the spatial statistics regarding the spatial autocorrelation Moran's I index, applied to understand the patterns of Chronic Kidney Disease (CKD) incidences in the area.

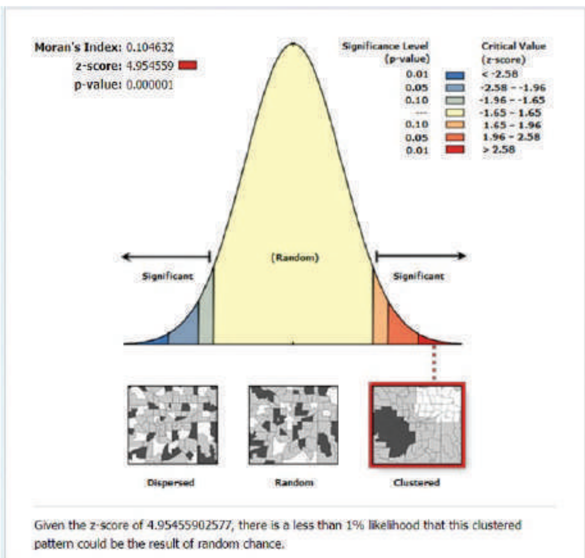

Figure 8. Spatial authocorrealtion statistics.

The results, as depicted in Figure 8 reveal a Moran's Index of 0.104632, a z-score of 4.954559, and a p-value of 0.000001. With a z-score as high as 4.954559, which indicate there is a less than 1% likelihood that the observed clustered pattern of CKD incidences is due to random chance. This significant statistical evidence supports the presence of non-random, spatially dependent factors influencing CKD distribution in the study area.

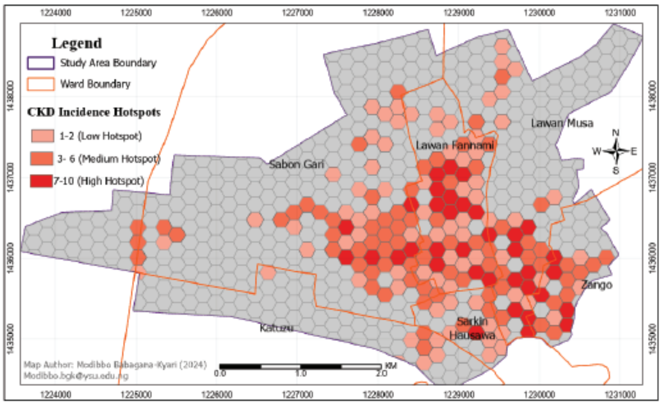

Figure 9. The classified three hotspots by incidence counts density.

The map in Figure 9 illustrates the incidence of Chronic Kidney Disease (CKD) across a surveyed area using hexagonal tessellation. It employs color coding to highlight three distinct clusters of CKD hotspots. Apparently, areas with the highest CKD incidence are marked by darker red hexagons, indicating high hotspots with values ranging from 7-10 cases. Medium hotspots, where CKD incidence is moderate (values of 3-6), are shown in lighter red. Regions with low CKD incidence, termed low spots, are represented by blue hexagons (values of 1-2). The survey area is delineated in grey. This visual representation provides a clear spatial distribution of CKD incidence, allowing for the identification of areas with varying disease prevalence in the study area as depicted in Figure 9.

Water Quality Exploration and CKD Incidence Using GIS

This section of the study focuses on analyzing groundwater quality in CKD hotspots within Northern Yobe State to identify potential environmental risk factors contributing to the prevalence of the disease. Figure 10 provides a visual representation of the geographical distribution of the water sampled locations. The blue dots indicate the locations of the 30 water facilities selected for analysis, which were strategically chosen across the identified disease hotspots as shown in Figure 10.

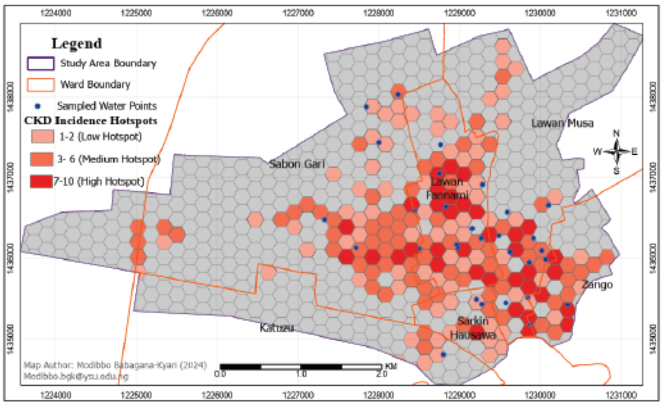

Figure 10. The locations of water points across the study area.

The map above clearly shows that the selected water points align with the hotspot polygons. Overall, the map effectively demonstrates the hotspot-based approach used for selecting the water samples in the area.

Water Quality Parameters in the Disease Hotspots

The analysis of water samples from disease hotspots examined the following parameters, (Arsenic, Cadmium, Lead, Mercury, Chromium, Fluoride, Nitrite, Nitrate, Sodium and phosphate as well as water hardnesses (Magnesium and Calcium) each essential for assessing water quality and its potential health impacts. These parameters and their observation are presented in Table 5.

Table 5. Descriptive statistics of water parameters across the three disease hotspots.

Serial No.	Parameters	High Hotspot (Min, Max, Mean)	Medium Hotspot (Min, Max, Mean)	Low Hotspot (Min, Max, Mean)	Benchmark Standard (WHO)
1	As(mg/L)	0.01-0.129, 0.0456	0.005-0.089, 0.0364	0.003-0.079, 0.0188	0.01 mg/L
2	Cd (mg/L)	0.021-0.317, 0.1081	0.009-0.173, 0.0604	0.000-0.020, 0.005889	0.003 mg/L
3	Pb (mg/L)	0.01-0.238, 0.0624	0.004-0.090, 0.0359	0.001-0.026, 0.008667	0.01 mg/L
4	Hg(mg/L)	0.002-0.02, 0.0058	0.000-0.005, 0.002	0.000-0.001, 0.000444	0.001 mg/L
5	Cr (mg/L)	0.048-0.552, 0.2441	0.014-1.67, 16.7963	0.005-0.080, 0.025111	0.05 mg/L
6	F (mg/L)	6.253-55.48, 25.385	1.78-34.48, 12.9546	0.9733-9.43, 3.278889	1.5 mg/L
7	Na (mg/L)	26.44-226.86, 111.12	7.43-137.42, 50.13	2.02-25.56, 9.88	200 mg/L
8	NO2 (mg/L)	0.2-16.84, 3.39	0.06-11.43, 2.39	0.03-2.95, 0.94	0.3 mg/L
9	NO3 (mg/L)	0.13-197.75, 56.86	4.96-92.92, 38.15	1.96-10.71, 5.39	50 mg/L
10	PO4 (µg/L)	194.72-209.97, 204.29	88.16-213.09, 192.76	186.68-671.51, 254.17	500 µg/L
11	Hardness-Ca (mg/L)	31.96-35.02, 33.89	14.7-35.48, 31.94	31.14-111.03, 42.13	200 mg/L (EPA)
12	Hardness-Mg (mg/L)	20.32-22.42, 21.36	16.26-22.28, 21.10	20.33-44.37, 23.98	150 mg/L (EPA)

The results in Table 5 present the descriptive statistics of water quality parameters tested across three CKD hotspots categorized as high, medium, and low within the study area. Several parameters, including arsenic (As), cadmium (Cd), lead (Pb), and mercury (Hg), were found to exceed the World Health Organization (WHO) benchmark standards, particularly in the high hotspot areas. For instance, fluoride (F) levels in the high hotspot areas showed a significant increased, with a mean concentration of 25.385 mg/L, far exceeding the WHO limit of 1.5 mg/L. Similarly, other contaminants like chromium (Cr), sodium (Na), and phosphates (PO4) also displayed elevated levels, particularly in the high hotspot, indicating significant environmental contamination. The data suggests a correlation between higher contaminant levels in groundwater and the increased incidence of CKD in these hotspots, underscoring the importance of addressing water quality as a potential risk factor for CKD in the region.

Spatial Relationship between Quality Parameters and CKD incidence

The Figure 11. depict the four maps showing the spatial distribution of Chronic Kidney Disease (CKD) incidences in relation to the concentrations of arsenic (As), cadmium (Cd), lead (Pb), and mercury (Hg), with blue dots representing sampled water points at the center of the study area. The analysis reveals that higher concentrations of these heavy metals often coincide with clusters of CKD incidences (denoted by red dots).

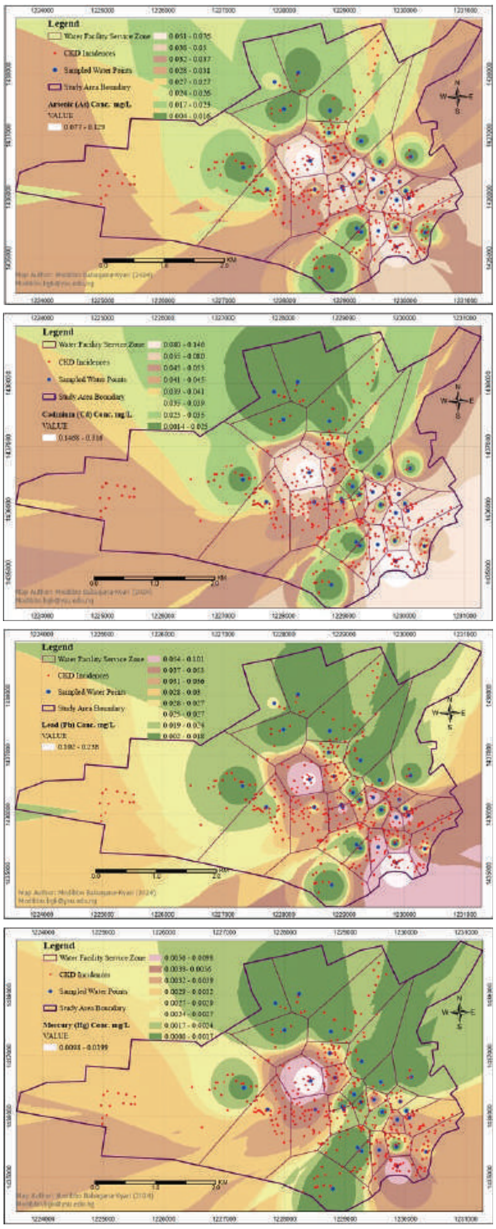

Figure 11. Maps for Arsenic, Cadmium, Lead and Mercury concentration level.

Notably, the maps illustrate that regions with elevated levels of arsenic, cadmium, lead, and mercury are associated with a higher density of CKD cases, suggesting a potential link between contaminated water sources and the prevalence of CKD. The sampled water points (blue dots) in the central area indicate critical locations for assessing water quality in relation to the surrounding CKD incidence, reinforcing the importance of monitoring these contaminants to understand their health impacts.

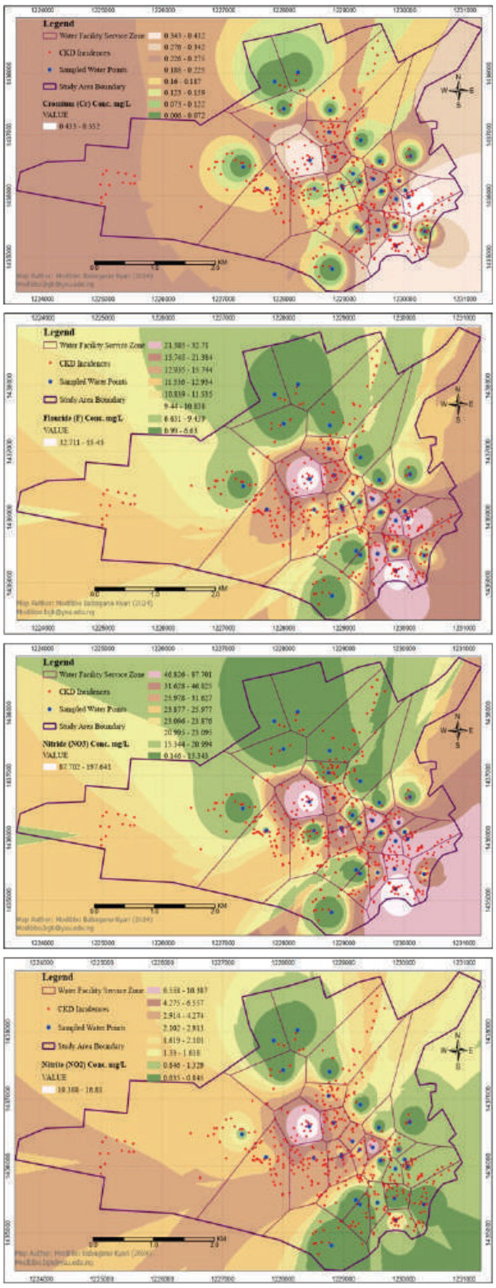

Figure 12. Maps for Chromium, Fluoride, Nitride, and Nitrite.

The four maps in Figure 12 depict the spatial relationship between CKD incidences and the concentrations of chromium (Cr), fluoride (F), nitrate (NO_3), and nitrite (NO_2) in the study area, showing a significant overlap between higher contaminant concentrations and areas with increased CKD cases. The darker shaded areas represent higher levels of these chemicals, which correspond to clusters of CKD incidences, particularly in the central and northwestern parts of the study area. This spatial pattern suggests that these contaminants may be linked to CKD prevalence, highlighting the need for an in-depth exploration.

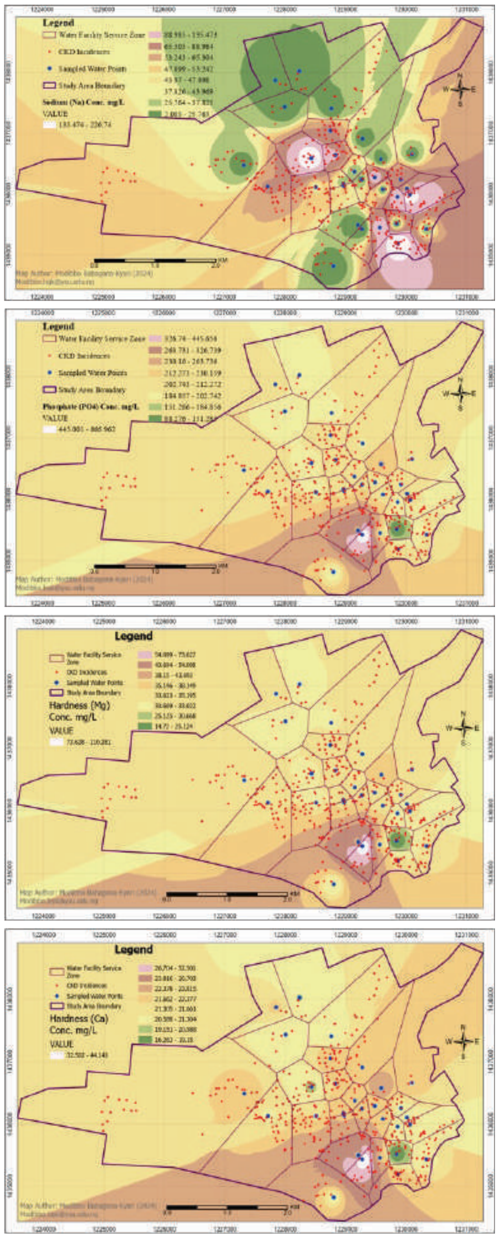

Figure 13. Maps for Sodium, Phosphate, water hardness (Mg), and (Ca).

Similarly, Figure 13 presents the spatial distribution of CKD incidences relative to sodium (Na), phosphate (PO_4), magnesium hardness (Mg), and calcium hardness (Ca) concentrations in the study area. A noticeable overlap is also observed between regions with higher concentrations of these elements and clusters of CKD cases. Specifically, elevated levels of sodium and phosphate in the central and southeastern parts of the study area align with significant CKD incidence pockets.

The maps for magnesium and calcium hardness further support this trend, as areas with higher hardness levels also correspond to CKD hotspots. Overall, in all the parameters particularly heavy metals, there are spatial correlation between the concentration of the disease incidence and water contaminants concentration.

Comparative Analysis of Contaminants Across CKD Hotspots

This section compares the water quality parameters across hotspots. The Box plot in Figure 14 depict the comparison of the observed parameters. Box plots are particularly useful for comparing these parameters against benchmark standards. This section details the use of box plots for comparative analysis, presenting the variations in water quality across the three CKD hotspots areas and their potential health implications.

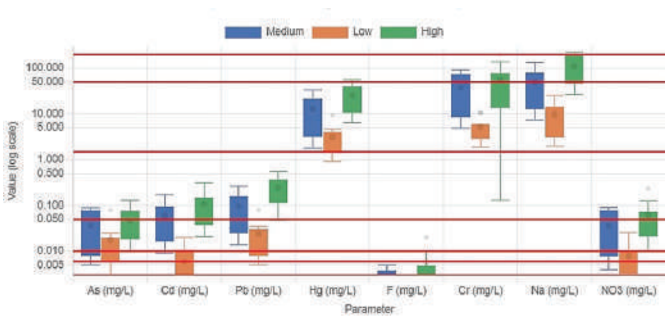

Figure 14. Comparison of water quality elements across CKD hotspots.

Figure 14 presents a comparative analysis of various water quality elements across three CKD hotspot levels Medium, Low, and High using a Box Plot on a logarithmic scale. The analysis shows that contaminant concentrations, such as arsenic (As), cadmium (Cd), lead (Pb), and mercury (Hg), are generally highest in the medium hotspot, followed by the High and Low hotspots, with most values exceeding recommended safety limits. The Medium hotspot also exhibits the greatest variability in contamination levels. Sodium (Na) and fluoride (F) levels peak in the High hotspot, while nitrate (NO_3) concentrations are highest in the medium hotspot. Overall, the Medium and High hotspots display significant contamination, with the Low hotspot having comparatively lower levels.

Water Quality Risk Assessment

This section present health risk assessment of the observed parameters using models such as Hazard Quotient (HQ) and Water Quality Index (WQI) to evaluate the potential health impacts of groundwater consumption in the study area.

Contaminant Hazard Quotients (HQ)

Contaminant Hazard Quotient (HQ) is a measure used to assess the health risks associated with exposure to specific contaminants in groundwater. Through calculating HQ values, the potential risk levels for different contaminants can be determined using their reference dose (RfD) standards (see, Goumenou et al., 2019). Figure 15 present the hazard Quotient (HQ) of each water parameters analyzed in the study. Find the reference dose of the parameters used for model in the link.

The Figure 15 is a line graph depicting the Hazard Quotients for various contaminants across three CKD hotspot (High, Medium and Low incidence areas). Each line represents a different contaminant (As, Hg, Cd, F, Pb, Cr, Na, PO4). The x-axis displays the Hotspot Levels, while the y-axis shows the Hazard Quotient values. The values were calculated using the HQ model. The colored legend identifies the average contaminants represented by each line. Arsenic, Mercury, Cadmium and Fluoride appeared to have high hazard quotient in the high hotspot. While in the low hotspot, virtually all the parameters except arsenic tend to have low HQ values (Figure 15).

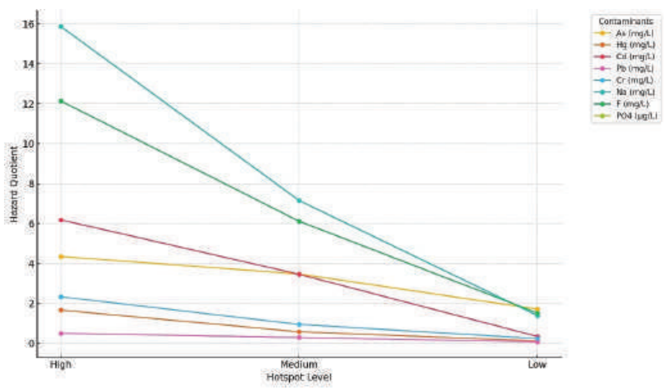

Figure 15. Hazard quotient of contaminants across the identified CKD hotspots.

Water Quality Index

Water Quality Index (WQI) is a comprehensive metric that summarizes the overall quality of water based on various parameters. It provides an easily interpretable indication of water safety for consumption. The below in Figure 16, present the calculated WQI values across the three disease hotspots comparing them to benchmark standards of WHO so as to identify regions with suboptimal water quality.

Figure 16 depict graphically the Water Quality Index (WQI) for selected parameters across three CKD hotspot levels: Medium, Low, and High. The box plot depicts the WQI distribution for each hotspot level, with WQI values on the y-axis and hotspot levels on the x-axis. The colored lines represent different water quality classifications: Excellent (WQI < 50), Good (50 ≤ WQI

< 100), Poor (100 ≤ WQI < 200), Very Poor (200 ≤ WQI < 300), and Unsuitable (WQI ≥ 300) respectively.

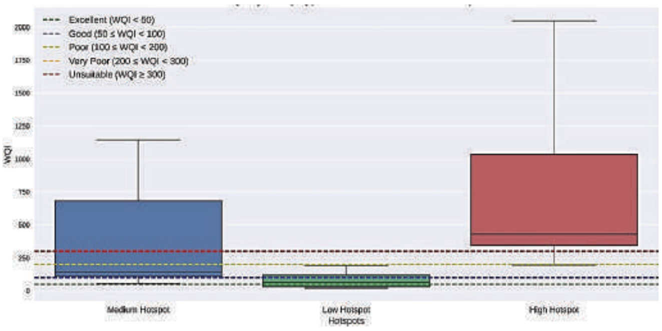

Figure 16. Water Quality Index (WQI) for selected parameters across hotspots.

Additionally, the WQI values for the Medium Hotspot range roughly, with most values falling into the Poor to Very Poor categories. The median WQI value is around 500, illustrating a significant contamination level. Conversely, the WQI values for the Low Hotspot are significantly lower than those of the Medium and High Hotspots. Most values fall within the Excellent to Good categories, with the median WQI value well below 50, indicating relatively clean water quality. The High Hotspot exhibits the highest WQI values, with a median value around 1000 and this clearly suggests that the water quality in this hotspot is predominantly Unsuitable, with significant contamination levels.

CKD and Household Water Usage Patterns

Analyzing household water usage patterns provides valuable context regarding community exposure to groundwater contaminants. The frequency and methods of groundwater usage were examined, shedding more light on behaviours influencing CKD risk factors. Specifically, the data for household water usage includes information on household water source, frequency of usage, duration of water usage and victims' period of residency.

Household primary source of water

The histogram in Figure 17 illustrates the primary water sources used by the CKD victim's household in the study area.

It can be seen from the chart a substantial majority, amounting to 66.89% of the population, rely on public handpumps for their water needs. Private boreholes follow at a significant 18.39%, while pure water/table water supplies 10.03% of the population. The remaining water sources, including harvested rainwater (0.33%), "I don't know" (0.50%), traditional hand-dug wells (0.84%), paddy shallow wells (1.34%), and open river water (1.67%) are used by a relatively small proportion of the population. These distributions signify a heavy dependence on public handpumps, highlighting their critical role in the community's water supply.

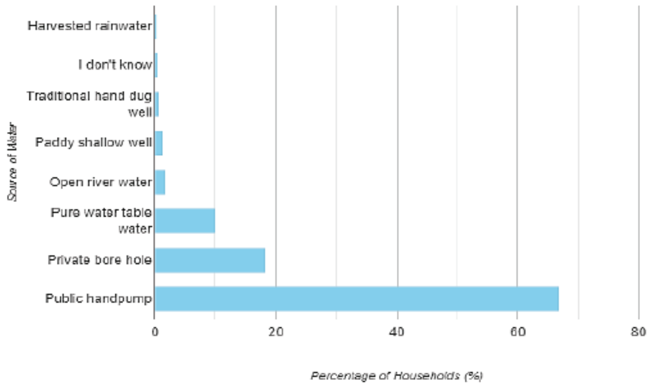

Figure 17. Primary source of water for victim's households.

Relationship between CKD rates and water quality in the study

The section presents the results on the relationship between water sources, CKD cases, and residency periods, portraying significant patterns crucial for understanding the impact of water quality on health over varying durations of residence. Figure 18 presents a heatmap illustrating the distribution of CKD cases across different water sources and residency periods. The x-axis categorizes water sources, while the y-axis represents residency periods in years. The color intensity of each cell corresponds to the number of CKD cases within that specific combination of water source and residency period as can be seen in the chart.

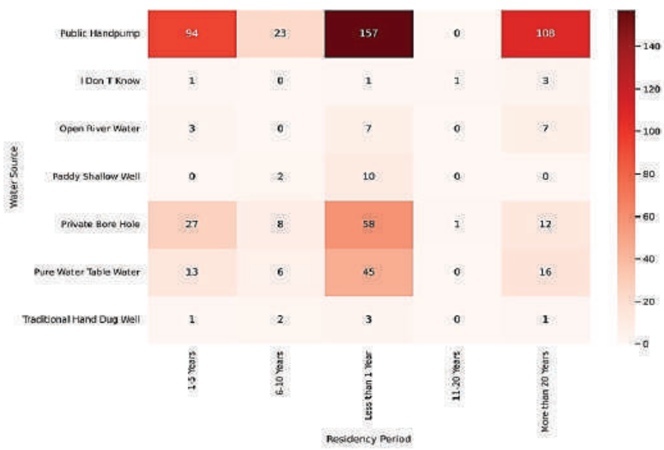

Figure 18. Distribution of CKD cases by water Source and period of residency.

The numbers in the heatmap boxes represent the count of Chronic Kidney Disease (CKD) cases for each combination of water source and victim's residency period in household. Each cell's color intensity varies according to the count, with darker shades indicating higher numbers of CKD cases. This visualization helps identify patterns or trends in CKD occurrences relative to different water sources and the length of residency of victims in households. The heatmap reveals a strong association between public handpumps and CKD cases, particularly among residents with a residency period of 11-20 years. A significant number of CKD cases were also linked to private boreholes across all residency periods. Conversely, water sources such as open river water, paddy shallow wells, and traditional hand-dug wells demonstrated lower frequencies of CKD cases.

Water quality variation across hotspots and water point types

The ANOVA conducted to analyze water quality parameters across three CKD hotspots revealed diverse levels of significance among different contaminants and ions. The F-statistic and corresponding p-values provided insights into the disparities in contaminant levels are presented in Table 6 below.

Table 6. ANOVA results for parameters across the three disease hotspots.

Parameter	F-statistic	P-value	Interpretation
Arsenic (As mg/L)	1.73	0.196	No significant difference
Lead (Pb mg/L)	3.39	0.049	Significant at the 0.05 level
Cadmium (Cd mg/L)	5.22	0.012	Significant difference
Mercury (Hg mg/L)	6.74	0.004	Highly significant difference
Chromium (Cr mg/L)	10.01	0.001	Highly significant difference
Fluoride (F mg/L)	7.2	0.003	Highly significant difference
Sodium (Na mg/L)	8.89	0.001	Highly significant difference
Nitrite (NO2 mg/L)	1.78	0.188	No significant difference
Nitrate (NO3 mg/L)	3.58	0.042	Significant at the 0.05 level
Phosphate (PO4 µg/L)	1.28	0.294	No significant difference
Hardness (Ca mg/L)	1.26	0.299	No significant difference
Hardness (Mg mg/L)	3.62	0.041	Significant at the 0.05 level

Source: Researchers' Analysis (2024)

It worth observing from the above Table 6, that Arsenic (As mg/L) parameter exhibited an F-statistic of 1.7299, associated with a p-value of 0.1963, suggesting that differences in arsenic levels across the hotspots are not statistically significant. Cadmium (Cd mg/L), on the other hand, showed more substantial variation, with an F-statistic of 5.2242 and a p-value of 0.0120, indicating significant differences in cadmium concentrations among the disease hotspots. This pattern of significant variation continued with Lead (Pb mg/L), which maintained an F-statistic of 3.3894 and a p-value of 0.0486, signifying marginal significance.

Similarly, it can be seen mercury (Hg mg/L) and Chromium (Cr mg/L) both demonstrated highly significant differences, with F-statistics of 6.7441 and 10.006, and p-values of 0.0042 and 0.0005, respectively. Notably, Fluoride (F mg/L) and Sodium (Na mg/L) also showed significant disparities, with F-statistics of 7.1983 and 8.8897, and p-values of 0.0031 and 0.0010, respectively, indicating noticeable distinction in their levels across the three disease hotspots.

In contrast, Nitrite (NO2 mg/L) and Phosphate (PO4 µg/L) indicate no significant differences with F-statistics of 1.7811 and 1.2809, and p-values of 0.1876 and 0.2941, respectively. Nitrate (NO3 mg/L), with an F-statistic of 3.5840 and a p-value of 0.0416, indicated significant differences, marking it as a parameter with notable variation.

These statistical results emphasize the spatial variation in water quality across the studied hotspots, with significant differences in several key parameters, implicating environmental or anthropogenic impacts influencing the variation.

Parameters variation across water points

Following the ANOVA, Tukey's HSD post-hoc tests were conducted to identify specific differences between pairs of hotspots particularly high and low hotspots. The Tukey's Honest Significant Difference (HSD) post-hoc test results presented compare water quality parameters between Deep Bore Hole and Hand Pump water points across different hotspots. The table delineates F-statistics and corresponding p-values for each parameter, highlighting statistical differences between the two water point types.

Relatively, for the Hand Pump water point type, the results indicated that the 'High hotspot' consistently exhibited higher levels of contamination compared to the 'Low hotspot' respectively. For instance, Cadmium (Cd) levels were significantly higher between the High and low hotspots with a mean difference of (0.1089) (p-value (0.001). Equally, Chromium (Cr) showed significant differences with a mean difference of (0.1160) (p-value (0.026)), and Sodium (Na) also demonstrated significant differences with a mean difference of (112.1762) (p-value (0.001) as clearly shown in Table 6.

Table 7. Tukey's HSD Post-hoc test for Deep Bore Hole and Hand Pump water points.

Parameter	Deep Bore Hole	Deep Bore Hole	Hand Pump	Hand Pump
	F-statistic	p-value	F-statistic	p-value
As (mg/L)	0.0699	0.9329	2.6246	0.1264
Cd (mg/L)	1.0462	0.3948	5.4256	0.0284
Pb (mg/L)	0.9400	0.4298	2.4539	0.1410
Hg (mg/L)	3.0053	0.1062	3.7681	0.0647
Cr (mg/L)	1.2070	0.3482	19.524	0.0005
F (mg/L)	0.9319	0.4326	11.419	0.0033
Na (mg/L)	1.1761	0.3566	17.023	0.0008
NO2 (mg/L)	0.9433	0.4286	2.0206	0.1884
NO3 (mg/L)	0.7901	0.4862	3.3697	0.0808
PO4 (Âµg/L)	0.0494	0.9520	1.1915	0.3474
Hardness (Ca) (mg/L)	0.0320	0.9685	1.1793	0.3508
Hardness (Mg) (mg/L)	0.3130	0.73980	1.3815	0.2997

The results Table 7, highlight the significant variations in water quality parameters across the hotspots for the Hand Pump water point type. The High hotspot consistently shows higher levels of contaminants such as fluoride, cadmium, sodium, chromium emphasizing the need for targeted interventions and further investigations. Overall, Tukey's HSD provides pairwise comparisons and is particularly useful in identifying which specific groups (hotspots) have significant differences.

DISCUSSION

Survey Characteristics Overview

This section provides a comprehensive overview of the key characteristics and findings of the survey conducted on chronic kidney disease (CKD). It includes details on consent rates, CKD incidence distribution, medical confirmation, household respondent demographics, educational background, and residency duration. These aspects collectively paint a picture of the survey's scope and the data's reliability, providing insights into CKD's prevalence and the community's engagement with the study.

Firstly, the survey achieved an exceptionally high consent rate, with 431 out of 430 respondents agreeing to participate. Even though some refusals were encountered in the course of the survey. This large consent rate indicates a strong willingness among the community to contribute to the study. Consequently, this indicates successful recruitment strategies. High participation rates are often associated with increased reliability and validity of the survey findings, as engaged participants are more likely to provide accurate and comprehensive data. Similarly, it also indicates that the local community are in serious need for uncovering root of the problem in the area.

Moreover, the distribution of CKD cases among surveyed households reveals that 92.6% of households reported at least one incidence of CKD, 2.46% reported two incidences, and 4.7% reported no CKD cases. This distribution highlights a high prevalence of CKD in the study area, suggesting that CKD is a significant health issue within the community. Therefore, such findings are consistent with research indicating that certain regions experience higher CKD prevalence due to local environmental or genetic factors forming hotspots (Friedman, 2019).

Additionally, out of 433 CKD cases surveyed, 98.1% were medically confirmed, while only 1.8% were not. This indicates the quality of the data reported as many of the disease victim's household presented medical records evidence to the field research assistants during the survey. Overall, the high rate of medical confirmation supports the accuracy and reliability of the reported CKD prevalence. Importantly, medical verification is crucial for ensuring the validity of health survey data, as it provides objective evidence of disease status. However, Self-reported disease incidence data through surveys can be a valid source of information in some instances, especially for hypertension, diabetes, and cancer in some settings (see, for example, Jeong et al., 2024).

Furthermore, the survey respondents included 37.44% household heads and 51% other household members, with CKD patients representing only 0.90% of respondents. The predominance of household heads among respondents suggests that the data collected reflects a comprehensive understanding of household health issues. Nevertheless, the low representation of CKD patients highlights a potential gap, likely due to the morbidity severity and mortality associated with the disease in the community as the disease victims eventually die when the disease manifest.

In addition, the majority of respondents (51.8%) had completed high secondary school, with 16.8% having informal education and 15.7% holding some college or a bachelor's degree. This educational profile indicates a generally high level of literacy and comprehension among respondents, which is beneficial for the accuracy of survey responses. Consequently, higher education levels are associated with better understanding of health survey questions and more reliable data (Van et al., 2013).

Finally, a significant portion of households (27.13%) had been residing in the area for more than 20 years, while only 6.05% had lived in the area for 1-5 years and 0.45% for less than a year. The long-term residency of many participants highlights the importance of considering environmental factors when assessing CKD risk particularly the water risk factors. Thus, prolonged exposure to local conditions may contribute to CKD prevalence, highlighting the need to advance research into environmental and lifestyle factors contributing to CKD (Floris et al., 2021).

Overall, this survey overview provides valuable insights into the community's engagement with the study, the prevalence of CKD, and the reliability of the data collected. Consequently, understanding these aspects is key for interpreting the survey findings and informing public health strategies and future research on chronic kidney disease.

Disease Spatial Prevalence Patterns

The significant clustering of Chronic Kidney Disease (CKD) cases in specific geographic hotspots, particularly around the sampled water facilities directly aligns with patterns observed globally in regions facing similar environmental health issues. Specifically, the spatial analysis in this study, utilizing Moran's I and hexagonal tessellation, clearly reveals that CKD cases are not randomly distributed but are concentrated in areas with poor water quality. Consequently, the result strongly supports the hypothesis that environmental factors, especially ground water risk factors, play a role in the etiology of CKD in the study region.

Interestingly, the observed geographic clustering of CKD cases in this study is consistent with findings from research conducted in Central America, South Asia, and other regions where CKD of unknown etiology (CKDu) is prevalent. Similarly, these studies have identified spatial clusters of CKD cases in agricultural and rural settings where water sources are often compromised by environmental contaminants and poor healthcare access (Orantes-Navarro et al., 2017; Jayasumana et al., 2015). Therefore, the spatial concentration of CKD in these hotspots effectively highlights the importance of localized environmental risk factors assessment, particularly those related to water quality.

Moreover, the spatial analysis using Moran's I and hexagonal tessellation in this study provides strong evidence of a potential environmental trigger for CKD, closely linked to water contamination. This pattern is further supported by a growing body of literature associating CKD with exposure to nephrotoxic substances in water, such as heavy metals and agrochemicals, particularly in regions reliant on groundwater affected by agricultural runoff (Wanigasuriya, 2012; Wesseling et al., 2013). Equally, similar spatial patterns have been documented in Sri Lanka and El Salvador, where higher CKD prevalence correlates with areas exhibiting elevated levels of these contaminants (Jayasumana et al., 2015; Crowe et al., 2019).

Consequently, the application of spatial analysis techniques, such as Moran's I and hexagonal tessellation, offers a robust framework for identifying and understanding the geographic patterns of CKD prevalence. Notably, Moran's I have been widely used to detect non-random spatial patterns, providing critical insights into the underlying environmental or socio-economic determinants of disease (Elliott & Wartenberg, 2004). Furthermore, hexagonal tessellation, with its ability to enhance the precision of spatial representation, corroborates the link between poor water quality and CKD incidence, thereby allowing for more targeted public health interventions (Mennis, 2006).

Ultimately, the spatial clustering of CKD cases in specific geographic hotspots, particularly those with poor water quality, underscores the critical role of environmental factors in the spatial epidemiology of CKD. These findings compellingly emphasize the need to address environmental determinants of health, particularly in regions with limited healthcare access, to effectively combat the growing burden of CKD in vulnerable communities. Therefore, future research should continue to explore these spatial patterns, carefully integrating environmental and socio-economic variables to develop targeted interventions aimed at mitigating CKD in affected regions.

Water Quality Implications

The analysis of water quality in the study area revealed concerning levels of contamination, particularly in the high hotspot regions where several parameters exceeded the World Health Organization (WHO) benchmark standards. The most striking finding was the significant elevation of fluoride (F) levels, with a mean concentration of 25.385 mg/L, which far exceeds the WHO limit of 1.5 mg/L. This is particularly alarming given that high fluoride levels are known to cause various health issues, including dental and skeletal fluorosis, and may exacerbate CKD conditions (Gupta et al., 2020). Similarly, the elevated levels of other contaminants such as arsenic (As), cadmium (Cd), lead (Pb), and mercury (Hg) further underscore the potential health risks faced by communities in these areas. The presence of these contaminants, especially in high concentrations, suggests significant environmental contamination, likely emanated through agrochemical residue runoff since the local engages in intensive paddy rice cultivation.

Spatial Analysis of Water Quality and CKD Incidence

The spatial analysis clearly illustrated a strong correlation between areas of high contaminant concentration and the density of CKD cases. Regions with elevated levels of arsenic, cadmium, lead, and mercury were particularly associated with higher incidences of CKD, supporting the hypothesis that water contamination is a significant environmental risk factor for CKD in the study area. This finding is consistent with global studies that have identified similar patterns, such as in regions of Central America and South Asia, where CKD prevalence is high in areas with contaminated water sources (Jayasumana et al., 2015). The spatial relationship depicted in Figure 12 between CKD incidences and the concentrations of chromium (Cr), fluoride (F), nitrite (NO_2), and nitrate (NO_3) emphasizes the need for quick interventions to remedy water contamination.

Comparison of Water Quality Across Hotspots

The comparative analysis of water quality across different CKD hotspots using Box Plots on a logarithmic scale revealed significant variability in contaminant concentrations. Interestingly, the medium hotspot exhibited the highest variability in contamination levels, with concentrations of key contaminants such as arsenic, cadmium, lead, and mercury generally highest in this hotspot, followed by the High and Low hotspots. This pattern suggests that the medium hotspot may be experiencing fluctuating environmental conditions or intermittent sources of pollution, which could be contributing to the variability (Figure 13). The high levels of sodium (Na) and fluoride (F) in the High hotspot further implicate these areas as critical zones for an intervention due to adverse nephrotoxic effects of these contaminants. This aligns with the findings of Waziri et al. (2017; Gashua et al. 2018; Yuguda et al., 2022), who previously identified heavy metal toxicity (Cadmium, lead and Arsenic, mercury) as a suspected environmental risk factors for the disease. More recently, Goni et al. (2024) also viewed poor groundwater quality as a contributing factor in the aetiology of the disease.

The hazard quotient (HQ) analysis revealed that arsenic, mercury, cadmium, and fluoride have high HQ values in the high disease incidence zone, indicating a significant health risk. Conversely, in the Low hotspot, most parameters tends to have low HQ values, suggesting relatively safer water conditions in these areas. This variation in hazard quotient aligns with the Water Quality Index (WQI) result, where the High hotspot displayed WQI values indicative of unsuitable water quality, with a median value around 1000. This stark contrast between the High and Low hotspots emphasizes the urgent need for environmental remediation in areas with poor water quality.

Mover, the reliance of 66.89% of the population on public handpumps highlights the critical role these water sources play in the community. The strong association between CKD cases and public handpumps, particularly among residents with 11-20 years of residency, suggests a chronic exposure to contaminated water sources. The heatmap analysis further supports this, showing that CKD cases are notably linked to public handpump across high residency periods, whereas open river water, paddy shallow wells, and traditional hand-dug wells exhibited lower frequencies of CKD cases. These findings suggest that interventions should prioritize the improvement of water quality in public handpumps and private boreholes, which are the primary sources of water for these communities. This is consistent with findings from Bihar, India, where Bhatia et al. (2014) reported high arsenic contamination in hand pump drinking water, with 57% of samples exceeding 200 ppb, posing significant health risks to residents. Similarly, Kumar et al. (2016) identified arsenic contamination in Buxar district, Bihar, noting correlations between contamination levels, well depth, and proximity to the Ganga River.

Furthermore, the ANOVA and Tukey's HSD tests confirmed significant spatial variation in water quality across the studied hotspots. Specifically, cadmium, lead, mercury, chromium, fluoride, and sodium levels showed statistically significant differences across the hotspots, with the High and Medium hotspots consistently exhibiting higher contamination levels compared to the Low hotspot. These findings are crucial as they indicate that certain water facilities, particularly hand pumps in high hotspots, are more prone to contamination. This may be due to factors such as proximity to pollution sources, geological conditions, or inadequate water treatment practices as rightly reported by (Gupta & Gupta, 2020). The significant differences identified through these statistical analyses emphasize the need for serious water quality monitoring and remediation efforts in the most affected areas such as reverse osmosis (RO).

Overall, the findings from this study highlight the critical role of water quality in the prevalence of CKD in the study area. The significant contamination levels observed, particularly in the High and Medium hotspots, suggest that addressing environmental and water management issues is essential to reducing the incidence of CKD.

Methodological Limitation and Future Study

This study encountered several limitations that should be considered when using the study findings. The cross-sectional design, while effective in identifying correlations, does not allow for the establishment of causal relationships between water quality and CKD prevalence. Furthermore, reliance on self-reported data for certain sociodemographic variables may introduce potential biases or inaccuracies. Although the study's spatial focus provides detailed insights into the specific area, it may limit the generalizability of the findings to other regions or populations.

Future research should investigate additional factors that may contribute to CKD risk, such as dietary patterns, occupational exposures, and genetic predispositions. Longitudinal studies would be valuable in providing more robust evidence of causal relationships between environmental contaminants and CKD. Expanding the research to encompass a broader geographic area could help determine whether the observed patterns are consistent across different contexts. Moreover, studies on the effectiveness of public health interventions aimed at improving water quality and healthcare access could offer critical insights into reducing CKD prevalence in affected regions.

CONCLUSION AND RECOMMENDATIONS

This study revealed a significant correlation between poor water quality and the prevalence of CKD in the identified hotspots. High concentrations of hazardous contaminants, including arsenic, cadmium, lead, and fluoride, were particularly prevalent in areas with higher incidences of CKD. The spatial analysis revealed a significant concentration of chronic kidney disease (CKD) cases in regions with the highest levels of water contamination, underscoring the substantial environmental influence on the disease's prevalence. This study reinforces the widely believe hypothesis that water quality risk factors may be a significant etiological factor contributing to CKD in Northern Yobe. The spatial correlations observed, alongside the consistency with previous studies, further validate this link, suggesting that environmental determinants like water contamination could play a critical role in the prevalence of CKD in the region.

The findings of this study emphasize the critical role of environmental factors, especially water quality, in the development and spread of CKD within the study area. The clustering of CKD cases in hotspots with poor water quality suggests that these environmental risks must be urgently addressed to halt the disease occurrence. The study findings highlight the need for a multifaceted approach to CKD prevention, focusing on environmental health, early detection thorough biomedical screening.

To address these issues, it is recommended that healthcare infrastructure and accessibility be significantly improved in the community so as to facilitate early diagnosis and effective treatment. Additionally, stringent water quality monitoring and regulation should be enforced in areas with identified poor water quality, including regular testing, remediation, and provision of alternative safe water sources as well as imposition of standards for drilling water point in the area. Finally, public awareness campaigns should be implemented to educate communities about CKD risk factors, particularly those associated with water quality, encouraging preventive behaviors and timely medical consultation to reduce the disease's impact.

REFERENCES

Baffa, A., Abdulkarim, I., & Yaro, N. (2021). Assessment of the spatial distribution of chronic kidney disease in Hadejia emirate, Jigawa state. *Bima Journal of Science and Technology, 5(1), 213-224.*

Babagana-Kyari, M. (2023). Exploratory GIS-based mapping and analysis of chronic kidney disease incidences in Gashua Town, Yobe State, Nigeria. *International Journal of Advances in Nephrology Research, 6(1), 31-45.*

Bhatia, S., Balamurugan, G., & Baranwal, A. (2014). High arsenic contamination in drinking water hand-pumps in Khap Tola, West Champaran, Bihar, India. *Frontiers in Environmental Science, 2, 49.*

Elliott, P., & Wartenberg, D. (2004). Spatial epidemiology: Current approaches and future challenges. *Environmental Health Perspectives, 112(9), 998-1006.*

Floris, M., Lepori, N., Angioi, A., Cabiddu, G., Piras, D., Loi, V., ... & Pani, A. (2021). Chronic kidney disease of undetermined etiology around the world. *Kidney and Blood Pressure Research, 46(2), 142-151.*

Fornace, K. M., Surendra, H., Abidin, T. R., Reyes, R., Macalinao, M. L., Stresman, G., ... & Cook, J. (2018). Use of mobile technology-based participatory mapping approaches to geolocate health facility attendees for disease surveillance in low resource settings. *International Journal of Health Geographics, 17, 1-10.*

Friedman, D. J. (2019). Genes and environment in chronic kidney disease hotspots. *Current Opinion in Nephrology and Hypertension, 28(1), 87-96.*

Gifford, F. J., Gifford, R. M., Eddleston, M., & Dhaun, N. (2017). Endemic nephropathy around the world. *Kidney International Reports, 2(2), 282-292.*

Goni, B. W., Kwairanga, H. S., Abdu, A., Ummate, I., Abdu, A., Ba'aba, A. I., ... & Caplin, B. (2024). High burden of chronic kidney disease of unknown cause among patients receiving renal replacement therapy in Northeast Nigeria: A cross-sectional survey of haemodialysis units. *medRxiv, 2024-06.*

Gupta, A., Kumar, B., Kumar, P., & Gupta, R. (2020). Prevalence of chronic kidney disease and its association with risk factors in Eastern Uttar Pradesh, India. *J. Clin. Exp. Nephrol., 5(4), 90.*

Goumenou, M., & Tsatsakis, A. (2019). Proposing new approaches for the risk characterisation of single chemicals and chemical mixtures: The source related Hazard Quotient (HQS) and Hazard Index (HIS) and the adversity specific Hazard Index (HIA). *Toxicology reports, 6, 632-636.*

Gupta, S. K., & Gupta, I. C. (2020). *Drinking water quality assessment and management*. Scientific Publishers.

Huang, Y., Wu, J., Li, X., & Chen, X. (2021). The application of GIS in environmental health research: Recent advances and future prospects. *Environmental Science & Technology, 55(3), 1234-1250.*

Jayasinghe, S., de Silva, K., & Senanayake, S. (2019). Community participatory approaches in the investigation of CKDu: An innovative model for disease mapping. *BMC Public Health, 19(1), 234.*

Jayasumana, C., Gunatilake, S., & Senanayake, P. (2015). Glyphosate, hard water and nephrotoxic metals: Are they the culprits behind the epidemic of chronic kidney disease of unknown etiology in Sri Lanka? *International Journal of Environmental Research and Public Health, 11(2), 2125-2147.*

Jayasumana, C., Paranagama, P., Agampodi, S., Wijewardane, C., Gunatilake, S., & Siribaddana, S. (2015). Drinking well water and occupational exposure to herbicides is associated with chronic kidney disease, in Padavi-Sripura, Sri Lanka. *Environmental Health, 14, 1-10.*

Jayatilake, N., Mendis, S., Maheepala, P., & Mehta, F. R. (2013). Chronic kidney disease of uncertain aetiology: Prevalence and causative factors in a developing country. *BMC Nephrology, 14(1), 180.*

Jeong, A., Tran, T. X. M., Moon, S. G., Kim, M. K., Kim, I., Kim, Y. M., & Park, B. (2024). Validation of self-reported morbidities of the Korean Atomic Bomb Survivor Cohort. *Epidemiology and Health*, e2024058.

Kumar, A., Rahman, M. S., Iqubal, M. A., Ali, M., Niraj, P. K., Anand, G., ... & Ghosh, A. K. (2016). Groundwater arsenic contamination: A local survey in India. *International Journal of Preventive Medicine, 7(1), 100*.

Luby, S. P., Saha, S., & Andrews, J. R. (2015). Towards sustainable public health surveillance for enteric fever. *Vaccine, 33, C3-C7*.

Lunyera, J., Mohottige, D., Von Isenburg, M., Jeuland, M., Patel, U. D., & Stanifer, J. W. (2016). CKD of uncertain etiology: A systematic review. *Clinical Journal of the American Society of Nephrology, 11(3), 379-385*.

Oliver, M. N., Matthews, K. A., Siadaty, M., Hauck, F. R., & Pickle, L. W. (2005). Geographic bias related to geocoding in epidemiologic studies. *International Journal of Health Geographics, 4, 1-9*.

Orantes-Navarro, C. M., Herrera-Valdés, R., Almaguer-López, M., López-Marín, L., Vela-Parada, X. F., Hernandez-Cuchillas, M., & Barba, L. M. (2017). Toward a comprehensive hypothesis of chronic interstitial nephritis in agricultural communities. *Advances in Chronic Kidney Disease, 24(2), 101-106*.

Priatna, D., & Monk, K.A. (2023) Progress, Challenges, and the Nexus of Research and Impact - the importance of technology in biodiversity conservation in Indonesia. *Indonesian Journal of applied Environmental Studies, 4(1): 3-9*. DOI: 10.33751/injast.v4i1.8778

Priyadarshani, W. V. D., de Namor, A. F. D., & Silva, S. R. P. (2023). Rising of a global silent killer: critical analysis of chronic kidney disease of uncertain aetiology (CKDu) worldwide and mitigation steps. *Environmental Geochemistry and Health, 45(6), 2647-2662*.

Rodriguez, R. A., Hotchkiss, J. R., & O'Hare, A. M. (2013). Geographic information systems and chronic kidney disease: Racial disparities, rural residence and forecasting. *Journal of Nephrology, 26(1), 3*.

Sanati, A. (2015). Chronic kidney disease mortality in Costa Rica; geographical distribution, spatial analysis and non-traditional risk factors. *LUMA-GIS Thesis*.

Saputro, B., Priatna, D., Rosadi, R., & Miyazawa, N. (2023). Spatial analysis of paddy field conversion in Purwakarta Regency, West Java, Indonesia. *Indonesian Journal of applied Environmental Studies, 4(1): 22-29*. DOI: 10.33751/injast.v4i1.6644

Sengupta, M., & Dalwani, R. (Eds.). (2008). *Proceedings of Taal 2007: The 12th World Lake Conference (Vol. 1)*. Ministry of Environment & Forests.

Siddique, K., Rafiq, M., Awan, A., Rehman, A., & Shaheen, M. (2013). Assessment of fluoride levels in drinking water and its health impacts in districts Peshawar and Charsadda, Pakistan. *Journal of Public Health, 21(1), 49-56*.

Smith, A. H., Lingas, E. O., & Rahman, M. (2010). Contamination of drinking-water by arsenic in Bangladesh: A public health emergency. *Bulletin of the World Health Organization, 78(9), 1093-1103*.

Van Der Heide, I., Wang, J., Droomers, M., Spreeuwenberg, P., Rademakers, J., & Uiters, E. (2013). The relationship between health, education, and health literacy: Results from the Dutch Adult Literacy and Life Skills Survey. *Journal of Health Communication, 18(sup1), 172-184*.

Vlahos, P., Schensul, S. L., Anand, S., Shipley, E., Diyabalanage, S., Hu, C., ... & Nanayakkara, N. (2021). Water sources and kidney function: Investigating chronic kidney disease of unknown etiology in a prospective study. *NPJ Clean Water, 4(1), 50*.

Wanigasuriya, K. P. (2012). Update on uncertain etiology of chronic kidney disease in Sri Lanka's north-central dry zone. *MEDICC Review, 14(2), 61-65*.

Weaver, V. M., Fadrowski, J. J., & Jaar, B. G. (2015). Global dimensions of chronic kidney disease of unknown etiology (CKDu): A modern era environmental and/or occupational nephropathy? *BMC Nephrology, 16(1), 145*.

Wesseling, C., Crowe, J., Hogstedt, C., Jakobsson, K., Lucas, R., & Wegman, D. H. (2013). Mesoamerican nephropathy: Report from the first international research workshop on MeN. *American Journal of Kidney Diseases, 63(3), 502-508*.

Xie, S., Greenblatt, R., Levy, M. Z., & Himes, B. E. (2017). Enhancing electronic health record data with geospatial information. *AMIA Summits on Translational Science Proceedings, 2017, 123*.

Appendix 1. Reference Doses for Contaminants

The following table summarizes the reference doses (RfD) for each contaminant, along with their sources and hyperlinks.

Contaminant	Reference Dose (RfD)	Source	Hyperlink
Arsenic (As)	0.0003 mg/kg/day	U.S. EPA IRIS	https://cfpub.epa.gov/ncea/iris/iris_documents/documents/subst/0278_summary.pdf
Mercury (Hg)	0.0001 mg/kg/day	U.S. EPA IRIS	https://cfpub.epa.gov/ncea/iris/iris_documents/documents/subst/0370_summary.pdf
Cadmium (Cd)	0.0005 mg/kg/day	U.S. EPA IRIS	https://cfpub.epa.gov/ncea/iris/iris_documents/documents/subst/0141_summary.pdf
Fluoride (F)	0.06 mg/kg/day	U.S. EPA IRIS	https://cfpub.epa.gov/ncea/iris/iris_documents/documents/subst/0053_summary.pdf
Lead (Pb)	0.0004 mg/kg/day	U.S. EPA IRIS	https://cfpub.epa.gov/ncea/iris/iris_documents/documents/subst/0277_summary.pdf
Chromium (Cr)	0.003 mg/kg/day	U.S. EPA IRIS	https://cfpub.epa.gov/ncea/iris/iris_documents/documents/subst/0144_summary.pdf
Sodium (Na)	0.2 mg/kg/day	WHO Guidelines for Drinking-water Quality	https://www.who.int/water_sanitation_health/dwq/guidelines/en/

Appendix 2. Reference Doses (RfD) for Contaminants

Contaminant	Reference Dose (RfD)	Source	Hyperlink
Arsenic (As)	0.0003	EPA	https://www.epa.gov/iris
Mercury (Hg)	0.0001	EPA	https://www.epa.gov/iris
Cadmium (Cd)	0.0005	EPA	https://www.epa.gov/iris
Fluoride (F)	0.06	EPA	https://www.epa.gov/iris
Lead (Pb)	0.0004	EPA	https://www.epa.gov/iris
Chromium (Cr)	0.003	EPA	https://www.epa.gov/iris
Nitrite (NO2)	0.1	EPA	https://www.epa.gov/iris
Nitrate (NO3)	1.6	EPA	https://www.epa.gov/iris
Hardness (Ca)	0.2	EPA	https://www.epa.gov/iris
Hardness (Mg)	0.2	EPA	https://www.epa.gov/iris
Phosphate (PO4)	0.03	EPA	https://www.epa.gov/iris

InJAST
Volume 5, Number 2, October 2024
Pages: 84-91

P - ISSN: 2722 - 0133
E - ISSN: 2722 - 0141
DOI: 10.33751/injast.v5i2.9811

Cimandiri Watershed, Sukabumi District: A dynamic model for optimizing water resources

YUSWANDI[1,2,*], DOLLY PRIATNA[1], ROSADI[1]

[1]Graduate School of Environmental Management, Pakuan University, Jl. Pakuan Kotak Pos 452, Bogor 16129, Indonesia
[2]Trade and Industry Agency of Sukabumi District, Komplek Gelanggang Pemuda, Cisaat,
Kabupaten Sukabumi43342, Indonesia

*Corresponding author: *yuswandiius@gmail.com*

Submitted 8 May 2024; Accepted 18 October 2024

ABSTRACT

Water is a very important element for human life. Humans cannot survive without water, therefore water is one of the basic needs for human survival. Water resources in Indonesia are abundant, but only a few can be utilized as drinking water. Of the total water available, only 5% is used for drinking water, while the rest is water that cannot be consumed before further treatment. In addition, the current trend is to reduce the supply of drinking water. In researching and evaluating the water resources of an area, the quantity and quality aspects must be considered because both factors are measures that need to be taken into account in the utilization of water resources. A water balance analysis is necessary to compare the water availability and demand in the Cimandiri Watershed in Sukabumi District. An overview of the state of the water balance in the Cimandiri Watershed in Sukabumi District is anticipated to be provided by this research. This study employs secondary data and is descriptive in nature, utilizing quantitative methods for data collection, processing, and analysis. This study approach comprises the following analyses: 2022–2052 surface water and groundwater sources; 2022–2052 population; industrial; tourism; agriculture and livestock water demand; as well as 2022–2052 water balance. The analysis of water availability and demand in 2052 showed that 263,639,967.40 m^3 of water was available and 76,738,969.50 m^3 of water was demanded. Thus, we must develop a strategy and take action to ensure that extra water is used effectively and responsibly, thereby establishing a buffer for future shortages while also benefiting the environment and the community.

ABSTRAK

Air merupakan elemen yang sangat penting bagi kehidupan manusia. Manusia tidak dapat bertahan hidup tanpa air, oleh karena itu air merupakan salah satu kebutuhan pokok bagi kelangsungan hidup manusia. Sumber daya air di Indonesia melimpah, namun hanya sedikit yang dapat dimanfaatkan sebagai air minum. Dari total air yang tersedia, hanya 5% yang digunakan untuk air minum, sedangkan sisanya merupakan air yang tidak dapat dikonsumsi sebelum diolah lebih lanjut. Selain itu, tren yang terjadi saat ini adalah berkurangnya pasokan air minum. Dalam meneliti dan mengevaluasi sumber daya air suatu daerah, aspek kuantitas dan kualitas harus diperhatikan karena kedua faktor tersebut merupakan ukuran yang perlu diperhitungkan dalam pemanfaatan sumber daya air. Analisis neraca air diperlukan untuk membandingkan ketersediaan dan kebutuhan air pada Daerah Aliran Sungai (DAS) Cimandiri di Kabupaten Sukabumi. Gambaran mengenai keadaan neraca air di DAS Cimandiri Kabupaten Sukabumi diharapkan dapat diperoleh melalui penelitian ini. Penelitian ini menggunakan data sekunder dan bersifat deskriptif dengan menggunakan metode kuantitatif dalam pengumpulan, pengolahan, dan analisis data. Pendekatan studi ini terdiri dari analisis berikut: sumber air permukaan dan air tanah tahun 2022–2052; jumlah penduduk tahun 2022–2052; industri; wisata; kebutuhan air pertanian dan peternakan; serta neraca air tahun 2022–2052. Analisis ketersediaan dan kebutuhan air pada tahun 2052 menunjukkan ketersediaan air sebanyak 263.639.967,40 m^3 dan kebutuhan air sebanyak 76.738.969,50 m^3. Oleh karena itu, kita harus mengembangkan strategi dan mengambil tindakan untuk memastikan bahwa kelebihan air digunakan secara efektif dan bertanggung jawab, sehingga dapat menjadi penyangga kekurangan air di masa depan sekaligus memberikan manfaat bagi lingkungan dan masyarakat.

Keywords: *Cimandiri, dynamic model, watershed, Sukabumi District, water balance*

INTRODUCTION

Water is an essential component for human survival. Humans cannot survive without water, hence it is one of the most basic need for survival. Furthermore, the UN's Sustainable Development Goals (SDGs) prioritize the availability and sustainability of clean water, which is a major priority for Indonesia's central and regional governments (Andriyanto et al., 2023; Rachmawati et al., 2024). Indonesia has an abundance of water resources, however only a small portion of them can be used for drinking. Only 5% of the total accessible water is used for drinking, with the rest being water that cannot be drunk without additional treatment (Triatmodjo, 2008). Furthermore, the current trend is to reduce the availability of drinking water. Water is critical to the survival of humanity and the environment since it is a source of life that cannot be replaced, and humans, animals, and plants cannot exist without it. Water has various uses beyond fundamental human needs, such as bathing, washing, and other domestic chores (Fulazzaky, 2014). Water resource management, as defined in Law of the Republic of Indonesia Number 17 of 2019 Concerning Water Resources, is required to maintain a balance between decreasing water availability and increasing water demand.

Water availability is strongly tied to water sources, whereas water demand is driven by fundamental community needs as well as other business or farming activities. Water cultivation requires supervision in order to monitor the use of water for economic activities. If water use is not managed and exceeds the carrying capacity, it will result in an imbalance between utilization and recharge of water resources in the recharge area (Cahyo et al., 2016).

The watershed (or called DAS in Indonesian) encompasses the entire jurisdiction of the river and its primary drainage (Kendarto et al., 2021). Therefore, the watershed border is a shadow line that runs along the top of a mountain, cliff, or hill, separating one flow system from another. According to this concept, the watershed is divided into two parts: the watershed which forms the upstream area, and the water distribution area which is downstream. (Fuady & Azizah, 2008). Sukabumi District has two water resources: surface water and groundwater. Both water resources are found in the Cimandiri Watershed, which includes 15 sub-districts: Bojong Genteng, Caringin, Cicantayan, Cibadak, Cicurug, Cidahu, Cikembar, Cikidang, Cisaat, Kadudampit, Kalapanunggal, Nagrak, Parakansalak, Parungkuda, and Warungkiara. In this location, there are numerous businesses and agricultural activities that use water. It is feared that this will have an impact on the water balance in these 15 subdistricts.

The purpose of this study is to develop a water balance model by calculating the comparison between existing water carrying capacity and the need for water for the community, other businesses, and cultivation activities, with the intention of optimizing the use of potential water resources in 15 sub-districts in Sukabumi District, which is located in the Cimandiri Watershed.

METHODS

Research Location

The study was undertaken in Cimandiri Watershed, Sukabumi District, which covers 15 sub-districts: Bojonggenteng, Caringin, Cicantayan, Cibadak, Cicurug, Cidahu, Cikembar, Cikidang, Cisaat, Kadudampit, Kalapanunggal, Nagrak, Parakansalak, Parungkuda, and Warungkiara (Figure 1). The research was conducted between January and September 2022.

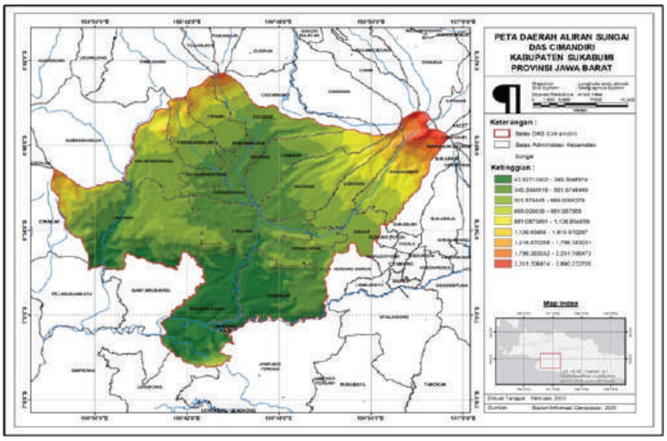

Figure 1. Map of the study area in Cimandiri Watershed, Sukabumi District.

Data Analyses

This descriptive quantitative research employs a dynamic system (Asmorowati & Sarasanty, 2021), to determine whether the water balance will be surplus or deficit over the next 30 years projected from 2022. The data used in analyzing the water balance in the Cimandiri Watershed were collected from various sources at the related agencies in Sukabumi District (Table 1). To establish if there is a surplus or deficit in the water balance, we compare water availability to water demand. Water availability in the Cimandiri Watershed in Sukabumi District is determined by the region's groundwater and surface water resources. Both water potentials are exploited in order to satisfy population's water needs as well as other economic activities. Water demand is determined using the basic water consumption for people, industry, tourism, agriculture, and livestock. This is due to the fact that in the research area, which spans 15 sub-districts of Sukabumi District, the only viable water resources are groundwater and surface water, whereas five activities account for the majority of water demand (Figure 2). The water balance analysis will evaluate the availability of water from surface and groundwater to the demand for water from industrial operations, tourism, agricultural, livestock, and population use, all provided in the form of a water balance.

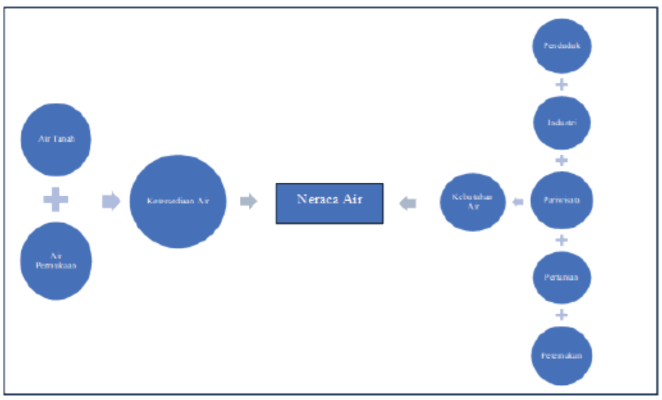

Figure 2. Water balance.

Table 1. Secondary data used in the research were collected from various sources in Sukabumi District.

Data Type	Data Form	Year	Sources
Cimandiri watershed in Sukabumi district	shp	2022	West Java Provincial Water Resources Office
Surface Water Potential	Numerical	2019	West Java Provincial Water Resources Office
Groundwater potential in 15 sub-districts in Cimandiri watershed	Numerical and shp	2019	Geological Agency, Ministry of Energy and Mineral Resources of the Republic of Indonesia and Central Bureau of Statistics of Sukabumi District
Total Population	Numerical	2021	Badan Pusat Statistik
Total Industry	Numerical	2021	Sukabumi District Trade and Industry Office
Total Livestock Population	Numerical	2021	Livestock Service Office of Sukabumi District
Number of Tourism Facilities and Infrastructure	Numerical	2021	Sukabumi District Tourism Office

After comprehending the ideas and operational definitions, as well as the research technique and design, the following phase in this study is to identify the three objectives of the study such as water carrying capacity, water demand, and water availability (Rejekiningrum et al., 2010). Each of the objects employed in this research analysis is described as follows: a). Water demand for population, industry, agriculture, livestock, and tourism (Figure 3); b). Water availability, including groundwater and surface water (Figure 4).

This study also developed a water balance model, which compares the total water demand of different sectors (i.e. raw water for people, industry, agriculture, livestock, and tourism) towards the availability of water resources which are groundwater and surface water (Purnama, 2013). Some computer programme and softwares such as Microsoft Excel, Powersim 10 Studio (Asmorowati & Sarasanty, 2021), as well ArcGIS version 10.8. were used to support the data analyses.

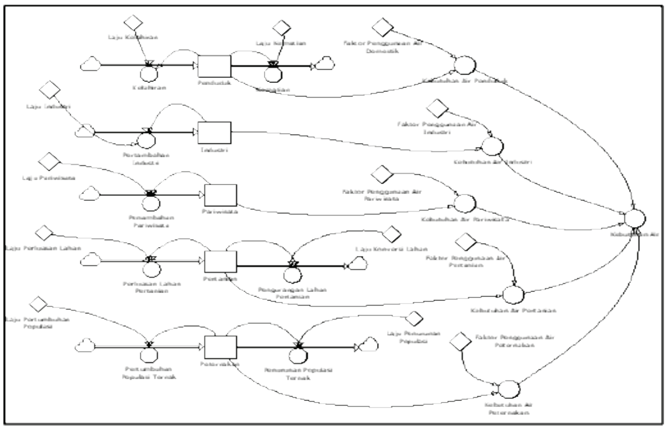

Figure 3. Water demand sub-system.

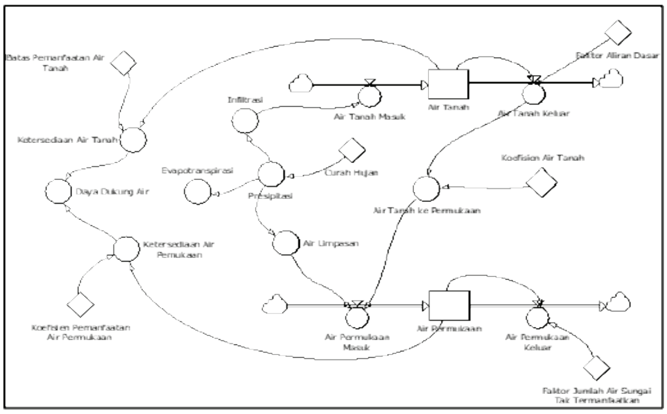

Figure 4. Water availability sub-system.

RESULTS AND DISCUSSION

Availability of Groundwater

Groundwater potential in 15 sub-districts of the Cimandiri Watershed in Sukabumi District was 56,409,120 m^3. The estimation of groundwater availability is impacted by rainwater infiltration, which accounts for 36% of groundwater availability. Groundwater availability also takes into account groundwater that emerges as springs and later serves as a recharge source for surface water. Groundwater springs have a base flow factor of 25.7%. The calculation findings show that groundwater availability will be 105,480,612.99 m^3 in 2052 (Figure 5).

Groundwater quality could be deteriorated due to overexploitation, resulting in land subsidence and other environmental issues (Tirtomihardjo, 2016). Studies show that the groundwater in the region of West Java, Indonesia, is primarily fresh, but the increasing extraction rates pose risks to its sustainability (Azy et al., 2016). Despite the critical role of groundwater in supporting urban and agricultural needs, the ongoing overexploitation raises concerns about long-term availability and environmental health. Sustainable management practices are essential to mitigate these challenges.

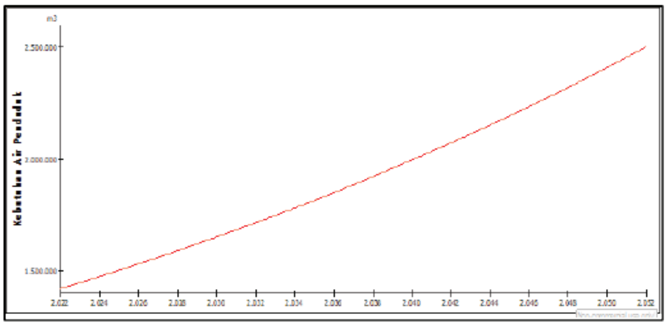

Figure 5. Graph of Groundwater availability rate 2022 - 2052 in Cimandiri Watershed of Sukabumi District.

Availability of Surface Water

Surface water availability in the Cimandiri Watershed in Sukabumi District is derived from the Cimandiri River's major tributaries, i.e. Cicatih (41.047 km long), Citarik (44.07 km long), and Cipelang (17.25 km long), as well as three other small tributaries, such as Cigadung, Cicareuh, and Citalahab. The average potential discharge from each site in the Citarik River is 23.65 m^3/second, enough to irrigate over 13,500 hectares of rice fields. The Cicatih river has an average discharge of 15.52 m^3/second, which can water almost 8,800 hectares of rice fields. The Cipelang River has an average discharge of 9.83 m^3/second, enough to irrigate almost 5,600 hectares of rice fields. The rate of surface water availability 2022-2052 in Cimandiri Watershed, Sukabumi District, can be seen in Figure 6.

The availability of surface water in West Java, Indonesia, is influenced by several interrelated factors, primarily climate change, land use changes, and socio-economic dynamics. These elements interact to affect water yield and distribution across the region, particularly in the Citarum River Basin, which has been the focus of multiple studies. Changes in rainfall patterns significantly impact water yield, with studies indicating that rainfall variations can account for 14.06% to 27.53% of changes in water yield (Nahib et al., 2021). Besides that, rising temperatures contribute to altered hydrological cycles, affecting evaporation rates and overall water availability (Jayanti, 2020). Furthermore, the conversion of land for agriculture and urban development has led to a decrease in water yield, with LULC changes contributing between 10.29% and 12.96% to water yield variations (Nahib et al., 2021; Nahib et al., 2022). Viewed from a socioeconomic standpoint, increasing population density raises water demand, leading to significant supply-demand imbalances, particularly during dry seasons (Mirrah & Kusratmoko, 2017). Besides that, agricultural practices, especially those reliant on water-intensive crops, place additional stress on available water resources.

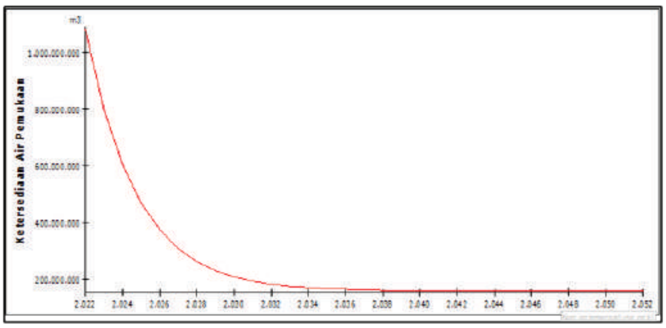

Figure 6. Graph of surface water availability rate 2022-2052 in Cimandiri Watershed of Sukabumi District.

Water Demand for Population

The water demand for the population in 15 sub-districts of the Cimandiri Watershed in the Sukabumi region is determined using the total population in 15 sub-districts and the percentage of the existing population's birth and death rates (Figure 7). The standard water requirement per person per day is also utilized as a criterion when calculating the population's water requirement. In 2021, the total population of 15 sub-districts will be 1,185,340, with a population birth rate of 2.3% and a population mortality rate of 0.4%. In urban areas, the average person needs 120 liters of water each day. In 2052, the population of 15 sub-districts demanded 2,501,783.3 m^3 of water. As the population grows year after year, so will the demand for water to meet basic necessities till 2052.

In West Java, Indonesia, the average groundwater requirement per person varies greatly between localities. According to research, socioeconomic characteristics and local infrastructure have an impact on home water usage. The average daily water consumption ranges from 117 liters in peri-urban areas to 214.3 liters in middle-class families. In suburban communities, individuals consume an average of 117 liters of domestic water per day, above the WHO's recommended range of 50-100 liters (Utami et al., 2023). Meanwhile, in a metropolitan city such as Bandung, the average daily consumption is reported to be 163.6 liters per person (Zevi et al., 2022).

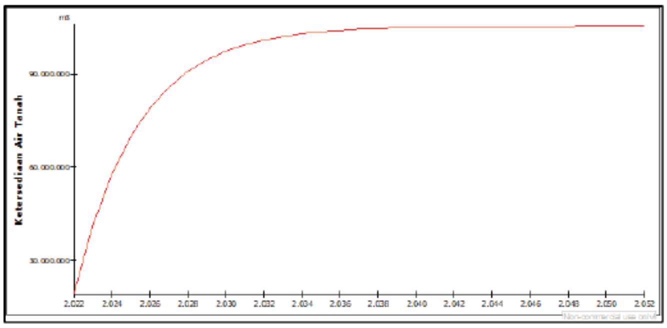

Figure 7. Graph of water demand rate for population 2022 - 2052 in Cimandiri Watershed of Sukabumi District.

Water Demand for Industrial

Medium to large industrial activities in the Cimandiri Watershed in Sukabumi District are mostly located in 15 sub-districts in the north of Sukabumi District. These industrial activities are activities that are taken into account in their water needs because these industrial activities use water for raw materials or supporting materials in relatively large quantities. The number of medium and large industrial activities in Sukabumi District from 2017 - 2021 fluctuated in line with the economic conditions affecting these industrial activities. In 2021, the number of industrial activities located in Sukabumi District (15 sub-districts in the Cimandiri

Watershed) amounted to 102 companies with a total water demand of 8,038,045 m^3 per year. The water demand in industrial activities is calculated using data on the amount of water consumed in one year. The rate of industry and industrial water usage parameters are also considered when calculating the water demand for industrial operations. For a 1% industrial growth rate, with an average water usage of 78,804.36 m^3. Water requirement for industrial purposes rises till 2052. The overall water consumption in 2052 was 10,834,069.86 m^3. The rate of water demand for industry 2022 - 2052 in Cimandiri Watershed, Sukabumi District, can be seen in Figure 8.

West Java, Indonesia, has a diverse industrial landscape that significantly influences water demand. The primary industries include agriculture, mining, and manufacturing, each contributing uniquely to the region's economic growth and water usage patterns. The mining sector, particularly for industrial minerals, plays a crucial role in West Java's economy, with a notable output multiplier effect (Soelistijo et al., 2015). Mining operations require significant water for processing and dust suppression, contributing to the overall water demand in the region (Juwana et al., 2009). The manufacturing industry, including food, textiles, and construction, accounts for a large share of the regional GDP (Falatehan & Bahtiar, 2019). This sector's water consumption is high due to processes such as cooling, cleaning, and product formulation, exacerbating water scarcity issues (Juwana et al., 2009).

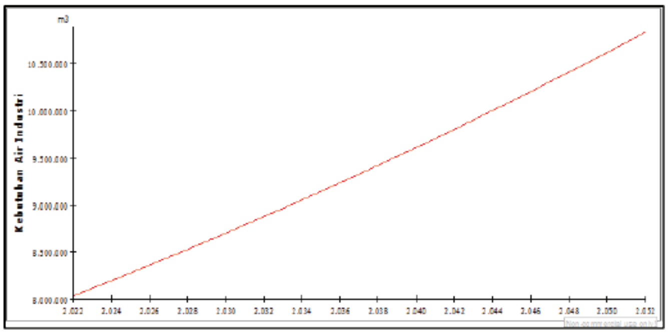

Figure 8. Graph of water demand rate for industry 2022 - 2052 in Cimandiri Watershed of Sukabumi District.

Water Demand for Tourism

Hotels, homestays, restaurants, and swimming pools (or water booms) are among the tourism-related businesses in the Cimandiri Watershed of Sukabumi District's 15 subdistricts. According to data from the Sukabumi District Tourism Office, the number of tourism-related economic activity has grown between 2017 and 2022. The total water consumption in tourism business activities fluctuates in response to tourist visits. Tourism business activity declined significantly between 2020 and 2021 as a result of the COVID 19 epidemic. The calculation of water demand in tourism activities accounts for a 3% tourism growth rate, with an average water demand of 775.96 m^3. According to the calculation of water consumption for tourism activities till 2052, it increased each year. In 2052, the water required to support tourism facilities and infrastructure totaled 88,522.55 m^3 (Figure 9).

The high average water consumption in Indonesia's tourism sector is primarily driven by several interrelated factors, including increased tourist demand, inadequate water management, and competition for water resources among various sectors. Hotels in Denpasar, Bali, for instance, are significant water consumers, relying on deep groundwater and municipal supplies, necessitating improved management practices to mitigate future shortages (Setiyono, 2018). Despite improvements in water supply coverage, the tourism sector still faces a significant gap between supply and demand, indicating reliance on alternative sources like groundwater (Yamamoto et al., 2021).

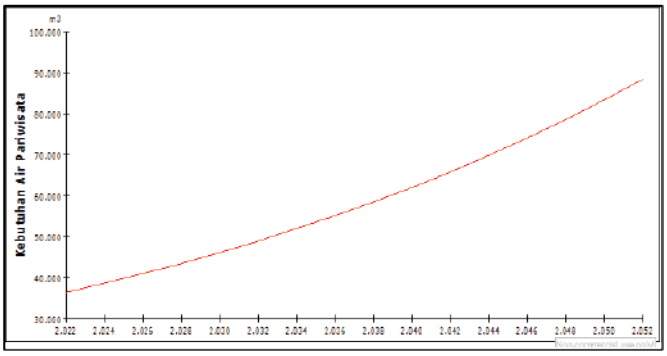

Figure 9. Graph of water demand rate for tourism in 2022 – 2052 in Cimandiri Watershed of Sukabumi District.

Water Demand for Agriculture

Sukabumi District's Cimandiri Watershed (15 sub-districts) has 20,883 hectares of irrigated agricultural land. The calculation of water demand for agricultural activities takes into account the growth and decrease of agricultural area, as well as the pace of expansion and conversion of agricultural land. According to Sukabumi District Agriculture Office data on land growth rates from 2018 to 2021, no new paddy fields were developed. The rate of conversion of paddy fields is also calculated by converting paddy fields into land other than rice fields, such as housing, industry, and road building. The rate of conversion of paddy fields is also calculated by converting paddy fields into land other than rice fields, such as housing, industry, and road building. According to data, paddy fields are converted at a rate of 9% annually. With no new agricultural area expansion and a 9% annual conversion rate, the demand for water in agriculture has declined until 2052. In 2052, agriculture will require 247,133.93 m^3 of water. The rate of of water demand for agriculture 2022-2052 In Cimandiri Watershed, Sukabumi District, can be seen in Figure 10.

Agriculture is one of the primary industries in West Java, Indonesia. The agricultural sector is vital, particularly in plantations, animal husbandry, and fisheries, which are major contributors to the local economy (Mukhyi et al., 2008). This sector's water demand is substantial, driven by irrigation needs and livestock maintenance, leading to increased pressure on water resources (Juwana et al., 2009).

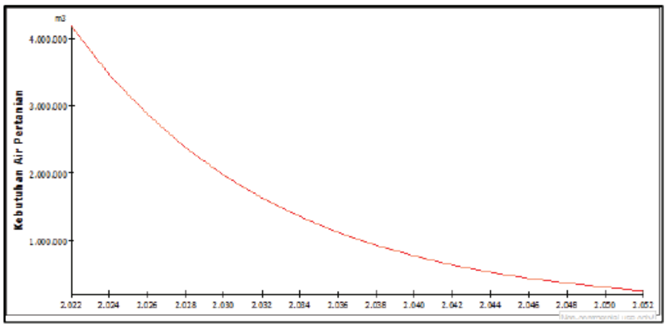

Figure 10. Graph of water demand rate for agriculture 2022-2052 In Cimandiri Watershed of Sukabumi District.

Water Demand for Livestock

Water demands for livestock production in a single year are determined using both direct water needs for livestock consumption and water needs for supporting facilities such as cage sanitation. According to data from Sukabumi District's Livestock Service Office in 2021, there are 12 types of livestock in the Cimandiri Watershed, with a total livestock population of 30,805,399 animals. The overall annual water consumption for all animals is 35,857,484.44 m^3. The rate of water demand for livestock 2022 - 2052 in Cimandiri Watershed, Sukabumi District, can be seen in Figure 11. The decline in water availability affects not only crop production but also the viability of livestock operations, necessitating a multifaceted approach to address these issues. Economic valuations indicate that cattle farming can yield greater benefits than traditional crop cultivation, especially in drought-prone areas (Widagdo et al., 2023).

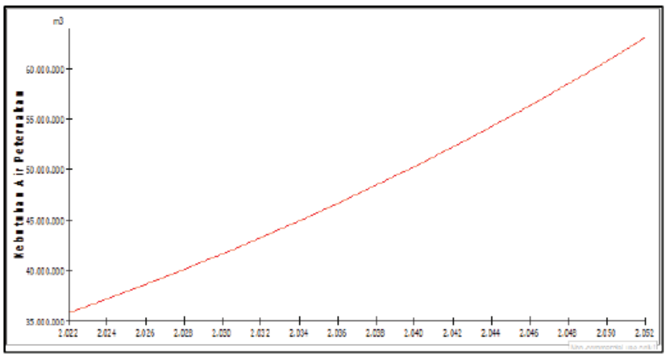

Figure 11. Graph of water demand rate for livestock 2022 - 2052 in Cimandiri Watershed, Sukabumi District.

Water Balance

Water balance can be analyzed up to a certain time period by calculating water availability from groundwater and surface water, as well as analyzing water demand from water needs for population, industrial activities, tourism activities, agriculture, and livestock. The results of the analysis show that the water carrying capacity of the Cimandiri Watershed in Sukabumi District can cover the water needs for various business operations as well as the fundamental needs of the present population until 2052 (Figure 12). According to the Water Balance research, there is still surplus water from 2022 to 2052, which tends to decline year after year as water demand increases. In the Table 2 can be seen that in 2052 predicted there is 186,900,997.90 m^3 of excess water.

The projected impacts of climate change on water balance in West Java, Indonesia, by 2050 are significant, with alterations in precipitation patterns, increased water demand, and extreme weather events. These changes threaten water availability and agricultural productivity, necessitating urgent adaptation strategies. Rainfall intensity and distribution are expected to shift, with projections indicating a potential increase in annual rainfall by 1,472 mm per year (Susanti et al., 2021).

Table 2. Water balance.

	(m^3)		
Year	**Kebutuhan Air**	**Daya Dukung Air**	**Neraca Air**
2022	49.539.360,48	1.100.863.900,80	1.051.324.540,32
2023	49.952.507,20	841.419.096,79	791.466.589,60
2024	50.413.846,70	661.935.294,66	611.521.447,96
2025	50.920.592,90	537.877.410,75	486.956.817,86
2026	51.470.239,21	452.211.409,76	400.741.170,55
2027	52.060.534,01	393.117.875,74	341.057.341,73
2028	52.689.458,19	352.400.793,28	299.711.335,08
2029	53.355.204,82	324.380.590,32	271.025.385,50
2030	54.056.160,60	305.124.392,05	251.068.231,45
2031	54.790.889,04	291.911.005,49	237.120.116,45
2032	55.558.115,14	282.859.237,42	227.301.122,28
2033	56.356.711,43	276.669.818,43	220.313.107,00
2034	57.185.685,36	272.446.311,41	215.260.626,06
2035	58.044.167,74	269.570.907,60	211.526.739,86
2036	58.931.402,31	267.618.345,89	208.686.943,59
2037	59.846.736,20	266.296.296,88	206.449.560,68
2038	60.789.611,33	265.404.107,49	204.614.496,16
2039	61.759.556,52	264.804.275,90	203.044.719,38
2040	62.756.180,38	264.402.746,61	201.646.566,24
2041	63.779.164,80	264.135.312,26	200.356.1476,46
2042	64.828.259,14	263.958.239,88	199.129.980,74
2043	65.903.274,82	263.841.817,03	197.938.542,22
2044	67.004.080,50	263.765.914,21	196.761.833,71
2045	68.130.597,72	263.716.937,97	195.586.340,24
2046	69.282.796,86	263.685.742,30	194.402.945,43
2047	70.460.693,58	263.666.199,50	193.205.505,92
2048	71.664.345,50	263.654.224,10	191.989.878,60
2049	72.893.849,30	263.647.107,81	190.753.258,51

2050	74.149.337,99	263.643.067,42	189.493.729,43
2051	75.430.978,50	263.640.938,30	188.209.959,81
2052	76.738.969,50	263.639.967,40	186.900.997,90

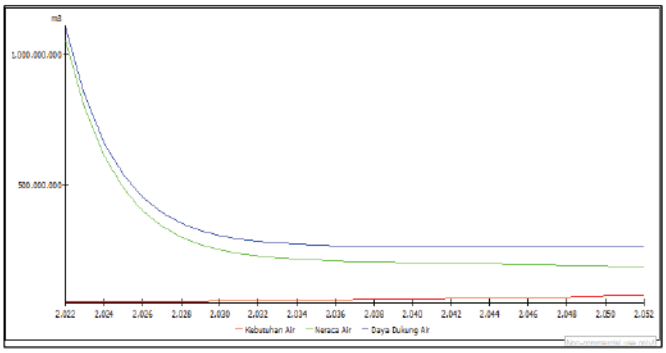

Figure 12. Graph of water demand rate with water support capacity 2022-2052.

CONCLUSION

The Cimandiri Watershed in Sukabumi District has enough surface and groundwater to meet the needs of the population, industry, tourism, agriculture, and livestock until 2052. A water balance analysis in the Cimandiri Watershed in Sukabumi district shows a water surplus of 186,900,997.90 m^3 till 2052. Thus, we must develop a strategy and take action to ensure that extra water is used effectively and responsibly, thereby establishing a buffer for future shortages while also benefiting the environment and the community.

REFERENCES

Andriyanto, N., Suheri, A., & Soesanta, P.E. (2023). Analysis of the sustainability status of community-based drinking water supply in Kapongan District, East Java. *Journal of Applied Environmental Studies, 4(2): 85-92*.

Asmorowati, E.T., & Sarasanty, D. (2021). Water availability model based on system dynamic: Sadar sub-watershed case study. *IOP Conf. Ser.: Earth Environ. Sci., 819 012089*: DOI 10.1088/1755-1315/819/1/012089

Azy, F.N., Sapari, M., Hadian, D., & Ismawan. (2016). Groundwater Characterization of Cihaur Watershed Basin, Batujajar and Adjacent, West Bandung District, West Java, Indonesia. *IOP Conf. Ser.: Earth Environ. Sci. 29 012027*. doi: 10.1088/1755-1315/29/1/012027

Cahyo, P.N., Hadi, M.P., & Adji, T.N. (2016). Pengaruh potensi sumber daya air terhadap pola penggunaan kebutuhan domestik di Kecamatan Eromoko Kabupaten Wonogiri. *Majalah Geografi Indonesia, 30(2): 196-206*. https://doi.org/10.22146/mgi.15649

Falatehan, F., & Bahtiar, R. (2019). Integration of Environmental and Economic Aspects in Green GRDP Calculation on the Industrial Sector in West Bandung District, Indonesia. *European Journal of Sustainable Development, 8(3): 152-162* doi: 10.14207/EJSD.2019.V8N3P152

Fuady, Z., & Azizah, C. (2008). Tinjauan daerah aliran sungai sebagai sistem ekologi dan manajemen daerah aliran sungai. *Lentera, 6, 1–10*.

Fulazzaky, M. A. (2014). Challenges of integrated water resources management in Indonesia. *Water (Switzerland), 6(7): 2000–2020*. https://doi.org/10.3390/w6072000

Jayanti, M. (2020). Climate change impacts on hydrology regime and water resources sustainability in cimanuk watershed, west java, indonesia. *International Journal of Geomate, 19(71): 90-97*. doi: 10.21660/2020.71.9215

Juwana, I., Perera, B.J.C., & Muttil, N. (2009). Conceptual framework for the development of West Java water sustainability index. *18th World IMACS / MODSIM Congress, Cairns, Australia 13-17 July 2009*. Australia.

Karolinoerita, V., Rifaie, F., & Munawaroh, M. (2022). Spatial-Temporal Changes in Water Supply and Demand in the Citarum Watershed, West Java, Indonesia Using a Geospatial Approach. *Sustainability, 15(1): 562*. doi: 10.3390/su15010562

Kendarto, D. R., Suryadi, E., Sampurno, R. M., & Cahyabhuana, A. P. (2021). Daya Dukung Sumberdaya Air dan Indeks Kekritisan Air Sub DAS Cisokan Hulu. *Jurnal Teknik Pertanian Lampung (Journal of Agricultural Engineering), 10(3): 402-412*. https://doi.org/10.23960/jtep-l.v10i3.402-412

Mirrah, A.A., & Kusratmoko, E. (2017). Application of GIS for Assessment of Water Availability in the Cianten Watershed, West Java. *IOP Conf. Ser.: Earth Environ. Sci. 98 012018*. doi: 10.1088/1755-1315/98/1/012018

Mukhyi, M.A., Sanim, B., & Sunarti, T. (2008). Analysis Role Subsector Agriculture and Sector Advantage to Economic Area Development of Province West Java: Approach Analysis IRIO. *Proceeding of the 2008 International Joint Conference in Engineering (IJCE 2008 August 4-5)*. Jakarta, Indonesia.

Nahib, I., Ambarwulan, W., Rahadiati, A., Munajati, S.L., Prihanto, Y., Suryanta, J., Turmudi, T., & Nuswantoro, A.C. (2021). Assessment of the Impacts of Climate and LULC Changes on the Water Yield in the Citarum River Basin, West Java Province, Indonesia. *Sustainability, 13(7): 3919*. doi: 10.3390/SU13073919

Nahib, I., Amhar, F., Wahyudin, Y., Ambarwulan, W., Suwarno, Y., Suwedi, N., Turmudi, T., Cahyana, D., Nugroho, N.P., Ramadhani, F., Siagian, D.R., Suryanta, J., Rudiastuti, A.W., Lumban-Gaol, Y., Karolinoerita, V., Rifaie, F., & Munawaroh, M. (2022). Spatial-Temporal Changes in Water Supply and Demand in the Citarum Watershed, West Java, Indonesia Using a Geospatial Approach. *Sustainability, 15(1): 562*. https://doi.org/10.3390/su15010562

Purnama, S. (2013). Penggunaan model dinamik dalam penentuan prioritas konservasi air tanah di Kabupaten Bantul. *Jurnal Teknik Lingkungan, 14(2): 115–120*.

Rachmawati, A., Priatna, D., & Rosadi. (2024). Evaluation of the Cipalabuan River's water quality and measures for reducing water pollution in the Sukabumi Regency. *Indonesian Journal of Applied Environmental Studies, 5(1): 20-24.* DOI: 10.33751/injast.v5i1.8203

Rejekiningrum, P., Pawitan, H., Indra Setiawan, B., & Kartiwa, B. (2010). Identifikasi Potensi Air Tanah Untuk Keberlanjutan Sumber Daya Air: Kasus Di Das CicatihCimandiri Kabupaten Sukabumi Jawa Barat. *Jurnal Sumber Daya Air, 6(1), 1–10*.

Setiyono, S. (2018). Disain Perencanaan Instalasi Pengolahan Air Limbah (Ipal) dan Re-use Air di Lingkungan Perhotelan. *Jurnal Air Indonesia, 5(2): 162-172*. doi: 10.29122/JAI.V5I2.2446

Soelistijo, U.W., Widayati, S., & Hamad, M. (2015). Analysis of Industrial Minerals Mining Sector in the Effort of Supporting the Economic Development of West Java Province, Indonesia. *American Journal of Earth Sciences, 2(5): 123-133*.

Susanti, I., Sipayung, S.B., Siswanto, B., Maryadi, E., Latifah, H., Nurlatifah, A., Supriatin, L.S., Witono, A., & Suhermat, M. (2021). Implications of extreme events on the water balance in Java. *AIP Conference Proceedings 2331, 030008*. doi: 10.1063/5.0042006

Tirtomihardjo, H. (2016). Groundwater Environment in Bandung, Indonesia. In S. Shrestha, V. P. Pandey, & S. Thatikonda (Eds.), *Groundwater Environment in Asian Cities*. Oxford: Butterworth-Heinemann (pp. 193-228). https://doi.org/10.1016/B978-0-12-803166-7.00010-6

Triatmodjo, B. (2008). *Hidrologi Terapan*. Cetakan ke-1. Yogyakarta: Beta Offset.

Utami, R.R., Geerling, G.W., Salami, I.R.S., Notodarmojo, S., & Ragas, Ad.M.J. (2023). Mapping domestic water use to quantify water-demand and water-related contaminant exposure in a peri-urban community, Indonesia. *International Journal of Environmental Health Research, 34(1): 625-638*. doi: 10.1080/09603123.2022.2163986

Widagdo, J.B.I.S., Sutrisno, D., & Setyono, P. (2023). Economic valuation of cattle farm development in Mondokan Sub-district, Sragen Regency. *IOP Conf. Ser.: Earth Environ. Sci. 1190 012046*. doi: 10.1088/1755-1315/1190/1/012046

Yamamoto, E.M.S., Sayama, T., & Takara, K. (2021). Impact of Rapid Tourism Growth on Water Scarcity in Bali, Indonesia. *Indonesian Journal of Limnology, 2(1): 1-16*. doi: 10.51264/INAJL.V2I1.14

Zevi, Y., Fatimah, W.M., Ramdani, Y., Habibbullah, M.Y., & Mursyida, N. (2022). Estimating household water consumptions in the Bandung Metropolitan area. *IOP Conf. Ser.: Earth Environ. Sci. 1065 012037*. doi: 10.1088/1755-1315/1065/1/012037

InJAST
Volume 5, Number 2, October 2024
Pages: 92-96

P - ISSN: 2722 - 0133
E - ISSN: 2722 - 0141
DOI: 10.33751/injast.v5i2.8513

Carbon dioxide (CO_2) emissions and mitigation efforts based on Bogor City's green open space

ANNISA CHOERINITA KUSUMA WARDHANI[1,2,*], RITA RETNOWATI, YOSSA ISTIADI[1]

[1]Graduate School of Environmental Management, Pakuan University, Jl. Pakuan No. 1, Tegallega, Bogor 16129, Indonesia
[2]Sekretariat Badan Penyuluhan dan Pengembangan SDM, Kementerian Lingkungan Hidup dan Kehutanan RI, Gd. Manggala Wanabhakti, Jl. Gatot Subroto, Senayan, Jakarta 10270, indonesia

*Corresponding author: *annisachoerinita@gmail.com*

Submitted 23 July 2024; Accepted 13 November 2024

ABSTRACT

One of the risks associated with climate change is carbon dioxide (CO_2) emission, which can negatively affect human health and the ecosystem. The CO_2 emission can lead to a decline in urban area quality that surpasses the environment's carrying capacity. This research aimed to investigate the relationship between CO_2 Emissions from Transportation (X_1), Household (X_2), and Business Sector (X_3) with the CO_2 reduction of green open space (Y). The hypothesis is that there is a negative correlation between CO_2 emissions from transportation, households, and businesses and CO_2 reduction from green open spaces. A quantitative research design was adopted using the Slovin formula and cluster random sampling. The Normality and Homogeneity Tests are used to analyze research data. The study yielded the following results: first, the coefficient of determination (r^2) = 0.003 indicates a relationship between CO_2 emissions from transportation with CO_2 reduction from green open space, with a 0.3% contribution. The second finding is that there is a 0.1% contribution from CO_2 reduction from green open space to the CO_2 emissions of households, as indicated by the coefficient of determination (r^2) = 0.001. Third, a correlation of 0.1% between CO_2 reduction from green open space and CO_2 emissions from the Business Sector is indicated by the coefficient of determination (r^2) = 0.001. Thus, using the regression equation $Y = 2320.432 - 0.16X_1 - 0{,}25\ X_2 - 0{,}007\ X_3$, there is an overall significant relationship between CO_2 emissions from transportation, CO_2 emissions from households, and CO_2 emissions from the business sector with the reduction of CO_2 from green open space.

ABSTRAK

Salah satu risiko yang terkait dengan perubahan iklim adalah emisi karbon dioksida (CO_2), yang dapat berdampak negatif terhadap kesehatan manusia dan ekosistem. Hal ini dapat mengakibatkan penurunan kualitas kawasan perkotaan hingga melampaui daya dukung lingkungan. Penelitian ini bertujuan untuk mengetahui hubungan Emisi CO_2 dari Transportasi (X_1), Rumah Tangga (X_2), dan Dunia Usaha (X_3) dengan penurunan CO_2 pada Ruang Terbuka Hijau (Y). Hipotesisnya adalah terdapat korelasi negatif antara emisi CO_2 dari transportasi, rumah tangga, dan dunia usaha dengan penurunan CO_2 dari ruang terbuka hijau. Dengan menggunakan rumus Slovin dan cluster random sampling, desain penelitian yang digunakan adalah kuantitatif. Uji Normalitas dan Homogenitas digunakan untuk menganalisis data penelitian. Penelitian ini menghasilkan hasil sebagai berikut: pertama, koefisien determinasi (r^2) = 0,003 menunjukkan adanya hubungan antara emisi CO_2 dari transportasi dengan penurunan CO_2 dari ruang terbuka hijau, dengan kontribusi sebesar 0,3%. Temuan kedua, terdapat kontribusi penurunan CO_2 dari ruang terbuka hijau terhadap emisi CO_2 rumah tangga sebesar 0,1% yang ditunjukkan dengan koefisien determinasi (r^2) = 0,001. Ketiga, korelasi sebesar 0,1% antara penurunan CO_2 dari RTH dengan emisi CO_2 dari Dunia Usaha ditunjukkan dengan koefisien determinasi (r^2) = 0,001. Dengan demikian, dengan menggunakan persamaan regresi $Y = 2320.432 - 0.16X_1 - 0{,}25\ X_2 - 0{,}007\ X_3$, secara keseluruhan terdapat hubungan yang signifikan antara emisi CO_2 dari transportasi, emisi CO_2 dari rumah tangga, dan emisi CO_2 dari dunia usaha dengan penurunan emisi CO_2 dari ruang terbuka hijau.

Keywords: *Bogor city, carbon dioxide emission, green open space*

INTRODUCTION

Climate Change is currently an issue that is quite important as a cause of climate anomalies in a region. For Indonesia, climate change poses a formidable challenge for its people, as it is the world's fourth most populous nation and the biggest archipelagic country (Priatna & Monk, 2023). The problem of global warming occurs throughout the world, including Indonesia. As the temperature increases by 1oC on the earth, it will impact ecosystems and species of flora and fauna, resulting in hydrometeorological disasters.

Greenhouse effect gases come from energy use such as the use of fossil fuels for industry and motorized vehicles, changes in forest land use to other areas, the livestock sector is produced from the decomposition of livestock manure, the agricultural industry produces CO_2 through the use of fertilizers, decomposing agrarian residues, and burning agricultural areas. Carbon dioxide gas (CO_2) is the largest contributor to emissions, at around 50%, compared to other greenhouse gases (Nugroho & Fazzry, 2016).

With increasing development and population growth today, in the next 100 years, CO_2 concentration levels in the atmosphere will increase twice compared to the industrial era, around 580 ppm (Akhadi, 2009). Based on these estimates, it will cause problems that impact the environment, and the earth's temperature will continue to increase yearly. CO_2 emissions can come from motorized vehicles, households, and the business sectors.

Household CO_2 emissions come from energy consumption using electronic devices (television, computer, refrigerator), cooking (LPG), and other activities. Total energy consumption in 2018 in the household sector is around 16%, and it is projected that in 2025, there will be an increase in the number of households by 70.6 million. The dominant energy used is electricity in 2018 by 60%, then the industrial, commercial, and other sectors. The dominant energy can be caused by the increasing level of people's income, which encourages the use of electronic goods (DEN, 2019).

Bogor has approximately 144.75 ha of urban forests, namely CIFOR's Dramaga Research Forest and the Bogor Botanical Gardens. In addition, several forms of green open space can absorb CO_2 (Nugraha et al., 2022). The results of the study by Dewi et al. (2024) show that the CO_2 absorption capacity of trees and green open space on one campus in Bogor, with an area of 35,000 m^2, is 282,784.89 kg per year. However, the area of green open space in Bogor City has been decreased from time to time (Dahlan 2008). Therefore, to reduce carbon dioxide emissions from households, transportation, and businesses in urban areas, one alternative is to optimize and maximize green open spaces, so research is needed. As a strategic urban area, Bogor City is expected to become an environmentally friendly, beautiful and comfortable city for residents and visitors from outside the city. Absorption of CO_2 through green open space in urban areas is one climate action that can contributed by the community and local government, which aligns with Sustainable Development Goal 13, "Climate Action", but it should also be synergized with the efforts from other sectors (Priatna & Khan, 2024).

METHODS

Data Collection and Analysis Techniques

In this study, the data analyzed included calculations of CO_2 emissions, divided into four factors: the size of green open space CO_2 reduction and analysis related to the calculation of emissions from transportation, emissions from households, and emissions from the businesses sector. The method used in this research is quantitative.

CO_2 Reduction of green open space

To determine the amount of CO_2 reduction, we measured the CO_2 absorption by plants. Based on the results of previous studies, it is known that the ability of each plant to absorb CO_2 is different. (Dahlan, 2007). The absorption capacity of CO_2 by plants in open space can be seen in Table 1.

Table 1. CO_2 absorption capacity by each species of plants.

No	Species	CO_2 Absorption Capacity (kg/tree/year)
1	*Pometia pinnata*	329.76
2	*Swietenia mahagoni*	295.73
3	*Swietenia macrophylla*	114.03
4	*Artocarpus heterophyllus*	126.51
5	*Tectona grandis*	135.27
6	*Manilkara kauki*	41.78

Source: Dahlan (2007)

CO_2 emission from transportation

The following formula is a formula to calculate the CO_2 emission from the transportation sector (IPCC, 2006).

CO_2 emissions = Fuel Consumption (lt) x Fuel EF x NVC Fuel

EF Benzine : 69.300 CO_2 kg/TJ

NVC Benzine : 33 x 10 $^{-6}$ TJ/lt

CO_2 emission from household

The following formula is used to calculate household emissions.

a) CO_2 emissions from household (LPG)

CO_2 emissions = FPG Consumption (kg) x EF LPG x NVC LPG

EF LPG : 63100 CO_2 kg/TJ

NVC LPG : 47.3 MJ/kg

b) CO_2 emissions from household (Electricity)

CO_2 emissions = Electricity Consumption (KWh) x Electricity EF

Electricity EF : 0.719 kg CO_2/KWh

c) CO_2 emissions household (waste)

CO_2 emissions = Consumption of Waste (kg) x EF of Waste

Waste EF : 2.56 kg CO_2/kg waste

CO_2 emission in the business sector

a) CO_2 emission of energy

CO_2 emissions = Mass of fuel (Gg) x Emission Factor (kg/TJ) x NCV (TJ/Gg)

EF LPG : 63100 CO_2 kg/TJ

NVC LPG : 47.3 MJ/kg

b) CO_2 emission of electricity

CO_2 emissions = EF x Electricity Consumption

EF : 0.000817 ton CO2/kWh (DEN, 2019)

RESULTS AND DISCUSSION

Relationship between CO_2 Emissions of Transportation with CO_2 Reduction of Green Open Space

In Figure 1, it can be seen that the direction of both correlations is negative because the line formed decreases. This correlation looks weak because the impact is minimal. The equation formed is Y=-0.1402X+ 5035.9.

Base on the ANOVA result, the F value obtained was 0.255 (Table 2). This F value is used in the F-test to evaluate the hypothesis in predicting the contribution of the independent variable (X_1) to the dependent variable (Y). If the value of Fcount > Ftable, then variable X is affected simultaneously by variable Y. It can be seen that the F count is 0.255 and a significance value of 0.722. Then $\rho_{y1} > 0$, there is a relationship between CO_2 Emissions Transportation and CO_2 reduction in green open space.

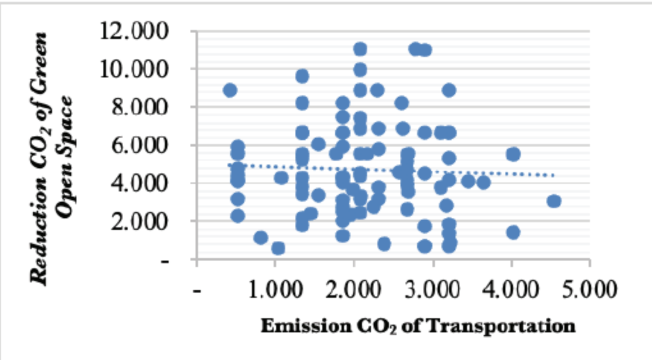

Figure 1. The scatter of the relationship between CO2 emissions of transportation and the CO2 reduction of green open space.

Table 2. ANOVA relationship between CO_2 emissions of transportation and the CO_2 reduction of green open space.

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	207448.411	1	208448.411	.255	.615[b]
	Residual	79823822.98	98	814528.806		
	Total	80031271.39	99			

Relationship between CO_2 Emissions of Households and CO_2 Reduction of Green Open Space

Figure 2 illustrates the relationship between Variable X_2 and Variable Y. The scatterplot reveals a negative correlation between the two variables. However, the association is weak, as evidenced by the scattered distribution of data points. The regression equation representing this relationship is Y = -0.0348 X+ 2350.5.

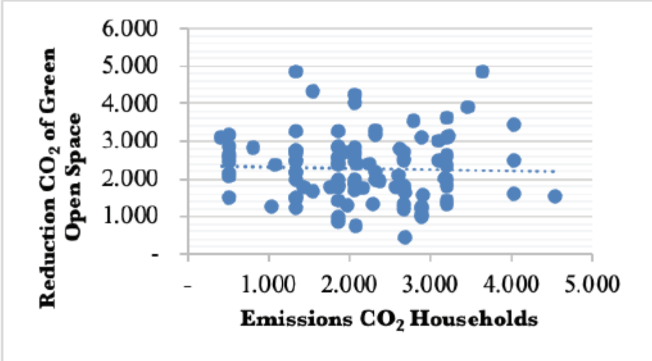

Figure 2. The scatter of the relationship between CO_2 emissions of households and the CO_2 reduction of green open space.

The one-way ANOVA test results revealed that the calculated F-value for the relationship between household CO_2 emissions and the CO_2 reduction provided by green open spaces is 0.128, with a significance value of 0.722 (Table 3). Since $\rho_{y2} > 0$, this indicates a relationship exists between household CO_2 emissions and the CO_2 reduction achieved by green open spaces.

Table 3. ANOVA relationship between CO_2 emissions of households and the CO_2 reduction of green open space.

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	104167.318	1	104167.318	.128	.722[b]
	Residual	79927104.07	98	815582.695		
	Total	80031271.39	99			

Relationship between CO_2 Emissions of Business Sector and the CO_2 Reduction of Green Open Space

Variabel X_3 and Variable Y are presented in Figure 3. It can be seen that the relationship between both variables is negative. The correlation has a weak or minimal impact, as seen from the slightly scattered points. The equation formed is Y = -0.1185X + 5853.1.

Based on the results of the one-way ANOVA test table, it was found that the significance value between CO_2 emissions of the business sector and the CO_2 reduction green open space is 0.722 (Table 4). This value indicates that ρ_{y3}> 0, then there is a relationship between CO_2 emissions of the business sector and the CO_2 reduction of green open space.

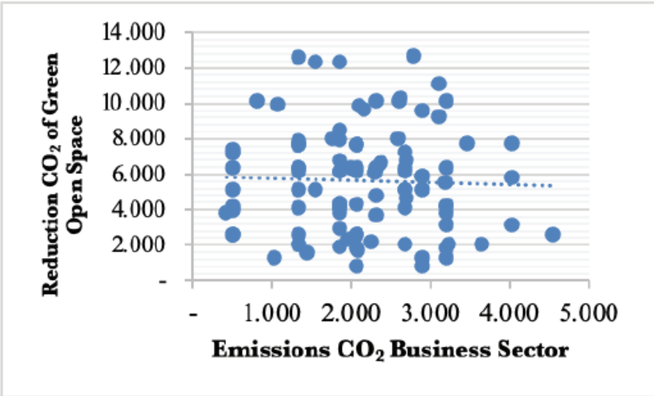

Figure 3. The scatter of the relationship between CO_2 emissions of the business sector and the CO_2 reduction of green open space.

Table 4. ANOVA relationship between CO_2 emissions of business sector and the CO_2 reduction of green open space.

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	104062.590	1	104162.590	.128	.722[b]
	Residual	79927208.80	98	815583.763		
	Total	80031271.39	99			

Relationship between Emissions CO_2 Transportation, Emissions CO_2 Households, Emissions CO_2 Business Sector with Reduction CO_2 of Green Open Space

The results of the R Square of 0.004 indicate that a value of 0.4% is the value of the CO_2 Emission effect Transportation to CO_2 Reduction green open space; the remaining 99.6% is influenced by other factors outside the model. It can be seen that the relationship between variables is not good because the value is below 50%. The R-value indicates the relationship between the independent and dependent variables with a value of 0.062, so the level of the relationship is very low.

Table 5. ANOVA relationship between CO_2 emissions of the transportation sector and the CO_2 reduction of green open space.

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	310167.798	3	103389.266	.103	.945[b]
	Residual	79721103.59	96	830428.162		
	Total	80031271.39	99			

Based on the results of the one-way ANOVA test table, it was found that the significance value between CO_2 emissions of households and the CO_2 reduction of green open space is 0.945. This value indicates that ρ_{y123}> 0, then there is a relationship between the CO_2 emissions of households and the CO_2 reduction of green open space.

CONCLUSION

The relationship between CO_2 emissions of transportation (X_2) and the CO_2 reduction of green open space (Y) has a negative direction of correlation and has the equation Y=-0.1402X+5035.9. There is a negative relationship between the CO_2 emissions of households (X_2) and the CO_2 reduction of green open space (Y). The equation for the relationship between the variables is Y= -0.0348X + 2350.5. The relationship between the CO_2 emissions of the business sector (X_3) and the CO_2 reduction of green open space (Y) has a negative relationship. The relationship between the two variables is as follows: equation Y=-0.1185X+5853.1. There is a relationship between the CO_2 emission of transportation (X_1), CO_2 emissions of households (X_2), and the CO_2 emissions of the business sector (X_3), all together with the CO_2 reduction of green open space (Y).

REFERENCES

Akhadi, M. (2009). *Ekologi Energi: Mengenali Dampak Lingkungan dalam Pemanfaatan Sumber-Sumber Energi*. Yogyakarta: Graha Ilmu.

Dahlan, E. N. (2007). Analisis ebutuhan Hutan Kota sebagai Sink Gas CO_2 Antropogenik dari Bahan Bakar Minyak dan Gas di Kota Bogor dengan Pendekatan Sistem Dinamik. [Disertasi]. Bogor: Institut Pertanian Bogor.

Dahlan, E. N. (2008). Jumlah Emisi Gas CO_2 dan Pemilihan Jenis Tanaman Berdaya Rosot Sangat Tinggi: Studi Kasus di Kota Bogor. *Jurnal Media Konservasi, 13(2): 85-89.*

Dewi, I.K., Febriani, Y., & Wicaksono, A. (2024). Carbon Dioxide (CO_2) sequestration by trees and green open space (GOS) at the campus of Pakuan University. *Indonesian Journal of Applied Environmental Studies, 5(1): 29-34.*

IPCC [Intergovermental Panel on Climate Change]. (2006). *Guidelines for National Greenhouse Gas Inventories – A primer*. Kanagawa, Japan: IGES. http://www.ipccnggip.iges.or.jp/public/2006gl

Nugroho, A., & Fazzry, B. (2016). Analisis Emisi Gas Rumah Kaca (CO_2) Angkutan Antar Kota Dalam Provinsi (AKDP) di Jawa Timur. *Prosiding SENIATI (BOOK-1), 2(1): 16-20*. DOI: https://doi.org/10.36040/seniati.vi0.980

Nugraha, L. M., Winarno, B., Fahmi, S., & Lestari, S. (2022). Opportunities and challenges of urban green open space for climate change mitigation and adaptation in Bogor, West Java. *IOP Conf. Ser.: Earth Environ. Sci. 1109 012013.*

Pratama, R. (2019). Efek rumah kaca terhadap bumi. *Buletin Utama Teknik, 14(2): 120-126.*

Priatna, D., & Khan, S.M. (2024). The importance of education and role of educational institutions in climate change mitigation and achieving UN SDG 13 "Climate Action". *Indonesian Journal of Applied Environmental Studies, 5(1): 1-5*. DOI: 10.33751/injast.v5i1.10559

Priatna, D., & Monk, K. A. (2023). Climate change and its implications on wildlife conservation. *Indonesian Journal of Applied Environmental Studies, 4(2): 64-66*. DOI: 10.33751/injast.v4i2.9661

DEN [Dewan Energi Nasional]. (2019). *Indonesia Energy Outlook 2019*. Jakarta: Kementerian ESDM.

InJAST
Volume 5, Number 2, October 2024
Pages: 97-108

P - ISSN: 2722 - 0133
E - ISSN: 2722 - 0141
DOI: 10.33751/injast.v5i2.9829

Factor analysis of waste management in Serang Regency, Indonesia

CAHYO HARSANTO*, **ISMAN KADAR, YOSSA ISTIADI**

Graduate School of Environmental Management, Pakuan University, Jl. Pakuan No. 1, Tegallega, Bogor 16129, Indonesia

*Corresponding author: *fcharsanto@gmail.com*

Submitted 13 May 2024; Accepted 13 November 2024

ABSTRACT

Serang Regency, with an area of 1,467.35 km^2 in 2020 had a population of 1,622,630 people. By referring to SNI 19-3983-1995, the waste capacity produced on average is 2.25 liters per person per day, so the potential waste in Serang Regency in 2020 is around 1,212,903.7 m^3/year, while the amount of waste that can be transported to the final waste processing site (or TPA) is 98,339 m^3. Based on this data, waste services in Serang Regency have only reached 7.37%, far from the target of the Serang District Regional Policy and Strategy (Jakstrada) of 74% as stated in the Serang Regency Regulation No. 6 of 2021. On the other hand, there are still many roadside piles of waste in Serang Regency, which indicates that there is still a lack of community participation in waste management. Waste management involves several factors, including institutions or organizations, laws, regulations, management financing, technical and operational waste, as well as community attention and participation. Looking at the phenomenon, analysis of waste management factors in Serang Regency was carried out so that the dominant factors in improving waste management performance could be identified for further planning of strategies to optimize waste management, both through waste handling and waste reduction. Based on the analysis carried out using SPSS, it can be stated that factors of operational technical, organizational, legal, and regulatory, as well as factors of financing and community participation are suitable to be used as a policy combination to improve waste management performance in Serang Regency.

ABSTRAK

Kabupaten Serang dengan luas wilayah 1.467,35 km^2 pada tahun 2020 mempunyai jumlah penduduk sebanyak 1.622.630 jiwa. Dengan mengacu pada SNI 19-3983-1995, kapasitas sampah yang dihasilkan rata-rata sebesar 2,25 liter per orang per hari, sehingga potensi sampah di Kabupaten Serang pada tahun 2020 adalah sekitar 1.212.903,7 m^3/tahun, sedangkan jumlah sampah yang dapat diangkut ke luas tempat pengolahan akhir sampah (atau TPA) adalah 98.339 m^3. Berdasarkan data tersebut, pelayanan persampahan di Kabupaten Serang baru mencapai 7,37%, jauh dari target Kebijakan dan Strategi Daerah (Jakstrada) Kabupaten Serang sebesar 74% sebagaimana tertuang dalam Peraturan Daerah Kabupaten Serang Nomor 6 Tahun 2021. Sementara itu, di Kabupaten Serang masih banyak terdapat tumpukan sampah di pinggir jalan, yang mana menunjukkan bahwa partisipasi masyarakat masih kurang dalam pengelolaan sampah. Pengelolaan sampah melibatkan beberapa faktor antara lain lembaga atau organisasi, peraturan perundang-undangan, pembiayaan pengelolaan, teknis dan operasional sampah, serta perhatian dan partisipasi masyarakat. Melihat fenomena yang ada, maka dilakukan analisis terhadap faktor-faktor pengelolaan sampah di Kabupaten Serang sehingga dapat diketahui faktor-faktor yang dominan dalam meningkatkan kinerja pengelolaan sampah untuk selanjutnya direncanakan strategi optimalisasi pengelolaan sampah, baik melalui penanganan sampah maupun upaya pengurangan sampah. Berdasarkan analisis yang dilakukan dengan menggunakan SPSS, dapat diketahui bahwa faktor teknis operasional, organisasi, hukum, dan peraturan, serta faktor pembiayaan dan partisipasi masyarakat layak dijadikan kombinasi kebijakan untuk meningkatkan kinerja pengelolaan sampah di Kabupaten Serang.

Keywords: *Community participation, factor analysis, financing, laws and regulations, waste management*

INTRODUCTION

The high rate of population growth in Indonesia and urbanization in cities is highly positively correlated with the amount of waste produced (Fauziah et al., 2023; Rachmawati et al., 2024), so this requires local governments to improve services to the community, one of which is preventing or handling the cleanliness of the residential environment. According to Rizal (2011), the increase in waste production is not commensurate with the waste handling process. This problem is of concern to local governments in planning strategies for managing waste problems, because waste problems are closely related to sanitation and clean water supply (Anshari et al., 2023; Rachmawati et al., 2024; Yuswandi et al, 2024), as well as significantly contribute to green gas house emission that has been causing climate change (Priatna & Monk, 2021; Anshari et al., 2023; Faqi & Wibawa, 2023; Priatna & Monk, 2023; Priatna & Khan, 2024; Wardhani et al., 2024).

Rizal (2021) explained that Indonesia generates approximately 64 million tons of waste annually. Around 60% of waste is managed at the Final Processing Site (TPA), around 10% is recycled, and the remaining 30% is discarded into the environment, including water bodies like rivers and seas. The policies implemented by the Indonesian government regarding the waste problem are contained in Presidential Regulation of the Republic of

Indonesia number 97, issued in 2017, which concerns National Policies and Strategies for Management of Household Waste and Similar Household Waste. Efforts to manage waste through 3R (Reduce, Reuse, and Recycle) are the main steps to reduce the emergence of waste, with a target of reducing community waste by around 30% by 2025. Monk & Priatna (2022) and Priatna & Khan (2024) stated that waste management is linked to all 17 Sustainable Development Goals (SDGs). In ongoing waste management efforts, regional governments in Indonesia - encompassing provinces, regencies, and cities - are responsible for managing household and similar waste at the Final Processing Facilities, aiming to achieve 70% waste management efficiency by 2025.

Serang Regency, with an area of 1,467.35 km^2, in 2020 had a population of 1,622,630 people (BPS Kabupaten Serang, 2021). By referring to SNI 19-3983-1995 (1995), the volume of waste capacity produced on average is 2.25 liters per person per day, so the potential waste in Serang Regency in 2020 is around 1,212,903.7 m^3/year, while the amount of waste that can be transported to the Final Waste Processing Site is 98,339 m^3 (DLH Kabupaten Serang, 2021). According to the data, waste management services in Serang Regency have only achieved coverage of 7.37%, which falls significantly short of the target set by the Serang District Regional Policy and Strategy (Jakstrada) at 74% (Serang Regency Regulation No. 6 of 2021). Conversely, in Serang Regency, the presence of numerous roadside waste piles suggests a potential lack of community involvement in waste management efforts.

Sudirman (2018) and Sudirman & Phradiansah (2019) identified several factors contributing to waste-related issues, including inadequate facilities, low public awareness of the importance of proper waste management, and insufficient attention from local authorities to address the problem. According to DLH Kabupaten Serang (2021), the main issue in Serang Regency is the absence of a designated Final Waste Disposal Site (TPA) to serve as the endpoint for waste management. Additionally, the region faces a limited number of waste transport vehicles and insufficient public awareness and participation, resulting in widespread illegal dumping, particularly along the roads within the area.

Waste management is considered effective when all its components operate harmoniously and support one another. Effective waste management involves several key elements, including institutions or organizations, legal and regulatory frameworks, financial support, technical and operational processes, as well as community awareness and participation. (Triani, 2017; Farid & Purba, 2020).

Considering the current waste management challenges in Serang Regency, this study analyzes the factors influencing waste management performance. The objective is to identify the dominant factors that can enhance waste management outcomes, which will inform the development of strategies to optimize waste management, including waste handling and reduction efforts.

METHODS

Research Design

This study on waste management factor analysis focuses on identifying the typology of waste management in Serang Regency and analyzing the factors influencing waste management within the region. The key factors include technical operations, organizational structure, financing, legal and regulatory frameworks, and community participation. This analysis will identify the dominant factors influencing waste management, enabling the development of more effective strategies to enhance waste management practices in Serang Regency.

Typology of waste management in Serang Regency

The study was conducted in Serang Regency, a district in Banten Province with a total area of 1,467.35 km^2, comprising 29 sub-districts and 326 villages. To identify the typology of waste management in the Serang Regency, the researchers employed interviews with the Serang Regency Environmental Agency and conducted field observations. This research falls under the category of descriptive studies, focusing on presenting data specific to waste management typologies within the region. The data collected pertains to various aspects of waste management (Damanhuri & Padmi, 2011), including:

a. Technical operational waste management such as data on waste generation, data on the number of waste management fleets, data on waste management facilities;
b. Organizations include institutions involved in handling waste management in Serang Regency;
c. Financing related to the financing required for waste management, including operations, maintenance, etc.;
d. Laws and regulations include any regulations in Serang Regency relating to waste management;
e. Community participation is how the people of Serang Regency play a role in waste management through 3R efforts (reduce, reuse, recycle) and paying waste levies.

Factor Analysis of waste management

This study employs quantitative methods (Xiao et al., 2017), specifically factor analysis, to examine waste management factors. Respondents were presented with 40 statements related to various aspects of waste management, and the responses were analyzed using factor analysis through the SPSS version 16 software. The analyzed factors (Figure 1) include waste operational techniques, financial aspects, organizational and institutional frameworks, legal and regulatory measures, and community participation.

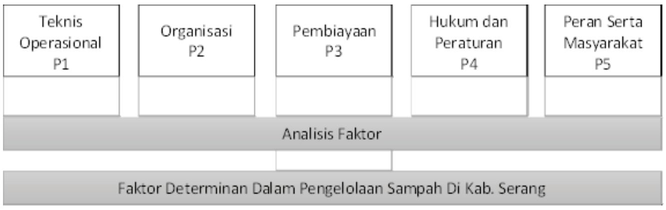

Figure 1. Factorial analysis.

The respondents for this factor analysis study will be individuals who have received waste management services from the government of Serang Regency. While Serang Regency comprises 29 sub-districts, not all communities are covered by these services. Therefore, the study's respondents are limited to the 6,041 households receiving waste management services (Table 1).

The factor analysis in this study employed a simple random sampling method, with the sample size determined using the Slovin formula at a 5% margin of error.

$$n = \frac{N}{1 + N e^2}$$

Where:
n = sample size
N = size of population
e = The acceptable error rate for the retrieval sample is 5%

Table 1. Determination of sample size.

Respondent	Unit (N)	e	N/(1+Ne^2)	Sample
Serang district community	6041	0,05	375,1591	375

The questionnaire assessed community responses in Serang Regency regarding current waste management practices, focusing on waste-related factors. The questionnaire was developed based on variables defined by the researchers and comprised closed-ended questions with response options provided on a rating scale. The collected data were analyzed using factor analysis through the SPSS 16 software. This analysis identified key factors influencing waste management, providing a foundation for developing strategic approaches to enhance waste management performance in Serang Regency.

The calibration of research instruments for factor analysis involves conducting validity and reliability tests to assess the alignment between the operational definitions and the measured research concepts. Additionally, these tests are essential for evaluating the stability and consistency of the research. Validity and reliability testing will focus specifically on non-test instruments in factor analysis.

To test the validity of non-test instruments, item analysis in this study was carried out by calculating the correlation coefficient for each item through a simple correlation test. The score for each item is X, and the total score minus X is Y. The formula used is Pearson Product Moment (PPM), namely:

$$r_{xy} = \frac{n \Sigma XY - (\Sigma X)(\Sigma Y)}{\sqrt{\{n\Sigma X^2 - (\Sigma X)^2\}\{n\Sigma Y^2 - (\Sigma Y)^2\}}}$$

To determine whether an item can be used for data collection, the correlation coefficient (r) is calculated and compared with the critical value of the Pearson Product-Moment correlation (r-table). If the calculated r-value (r-count) is greater than or equal to the critical r-value (r-table), the item is deemed suitable for data collection. Conversely, if the r-count is less than the r-table, the item is considered unsuitable for data collection.

For the reliability testing of non-test instruments, the reliability coefficient was calculated only for the valid items—those that were deemed suitable for data collection based on the results of the validity test. The formula used is Cronbach's Alpha as follows:

$$\alpha = \frac{n}{n-1}\left(1 - \frac{\Sigma Si^2}{St^2}\right)$$

Where:
α = Reliability coefficient
n = Number of item (valid only)
Si^2 = Number of variance of scored item
St^2 = Total of variance

Factorial analysis of waste management using SPSS through the following stages:

1. Open a new SPSS worksheet, then in the variable view, fill in the Name, label, and measure. In the waste management factor analysis research, names are filled with the codes TO1, O2, P3, H4, and PE5, which are codes for Technical Operations as variable 1, Organization variable 2, Financing variable 3, Laws and Regulations variable 4, Community Participation variable 5. In the label column, fill in the aspects of waste management outlined in the questionnaire (technical operations, organization, financing, laws and regulations, and community

participation). In the measure column, use the scale method;

2. Next, return to the datasheet view and enter the numbers/data from the questionnaire results from 5 aspects into columns 1 to 5. The table is filled in according to the number of respondents, in this case 375 samples;
3. From the SPSS menu, analyze, dimension reduction, then factor;
4. Then the factor analysis dialog box appears and moves the data from the left column to variables, then click descriptives;
5. In the dialog box, "Factor analysis descriptives are marked with the initial solution, KMO and Bartlett's test, and anti-image";
6. Next, click extraction and check the unrotated factor solution and scree plot;
7. Next, click rotation, activate Varimax, check the rotation solution, and continue;
8. Then click scores, and a dialog box will appear and activate save as variable. Then, click continue and OK to proceed with the factor analysis process.

Interpretation of the process results in factor analysis using SPSS is as follows:

1. In the SPSS application, analyze KMO and Bartlett's Test. The output of the KMO and Bartlett's Test results is used to determine whether a variable is appropriate and whether the factorial analysis process can be continued. The way to find out is by checking the value of the KMO MSA (Kaiser-Meyer_Olkin Measure of Sampling Adequacy). If the KMO MSA value obtained is greater than 0.50, this factor analysis can be processed further.
2. Anti-image Matrices are used to determine what variables are appropriate/worth using in a factor analysis. The numbers with the letter code (a) in the table are the Measure of Sampling Adequacy (MSA) results.
3. Total Variance Explained Table. This table presents the values for each variable analyzed in the study. Five variables were identified in the factor analysis of waste management, corresponding to five components for analysis. SPSS provides two types of analyses to explain the variance: Initial Eigenvalues and Extraction Sums of Squared Loadings. The Initial Eigenvalues analysis identifies the factors that are formed.
4. The Scree Plot provides a visual representation of the number of factors generated. Factors with Eigenvalues greater than 1 are identified and categorized as the factors extracted through the factor analysis process, labeled sequentially as Factor 1, Factor 2, and so on.
5. Then, to determine which factor the variable being analyzed falls into, this can be done by looking at the largest correlation value between the variables and the factors (components) formed.

RESULTS

Typology of Waste Management in Serang Regency

According to the 2020 Regional Policy and Strategy Study (Jakstrada) Waste Management Document, Serang Regency is one of the regencies in Banten Province, located at the northwestern tip of Java Island (DLH Kabupaten Serang, 2021). It covers an area of 1,467.35 km² and comprises 29 sub-districts and 326 villages. Geographically, Serang Regency lies between coordinates 105°7´ – 105°22´ East Longitude and 5°50´ – 6°21´ South Latitude. Serang Regency Boundaries are as follows:

North	: borders the Java Sea/Banten Bay
South	: borders Lebak Regency and Pandeglang Regency
West	: borders Cilegon City and Sunda Strait
East	: borders Tangerang Regency

In Serang Regency, waste management is governed by Serang Regent Regulation No. 21 of 2021, which amends Regulation No. 93 of 2017 regarding delegating certain regent authorities to subdistrict heads. Under this regulation, responsibility for waste management is not solely held by the Environmental Agency; it is also delegated to 15 subdistricts. The institutions responsible for waste management are as follows: a. Environmental Agency and UPT Waste management; b. Anyar District; c. Cinangka District; d. Kramatwatu District; e. Ciruas District; f. Kragilan District; g. Kibin District; h. Cikande District; i. Baros District; j. Pabuaran District; k. Ciomas District; l. Padarincang District; m. Tanara District; n. Tirtayasa District; o. Pontang District; and p. Waringin Kurung District.

From a technical and operational standpoint, the waste storage system in residential areas of Serang Regency is poorly managed. In some households, waste is stored in trash bins; in others, it is piled on the ground and subsequently burned. Each household is responsible for providing its waste storage system.

The waste transportation from households receiving waste management services is carried out by institutions or individuals designated by the community. Waste is first transported to Temporary Storage Sites (TPS) and subsequently transferred by the waste management fleet to the Final Processing Site (TPA). As of 2018, the Serang District Government had constructed 172 TPS units. Since 2019, the responsibility for TPS development has shifted to village governments, which manage construction based on local needs.

Waste management facilities such as TPS3R and TPST are operational in several villages and sub-districts. Serang Regency hosts four TPS3R units and one TPST unit (Table 2). Waste management at TPS3R facilities includes sorting economically valuable waste and processing organic waste through composting or maggot cultivation. The TPST unit in Serang Regency employs an incineration processing method and converts household waste into processed fuel (BBJP) using Refuse-Derived Fuel (RDF) technology. For final waste disposal, Serang Regency collaborates with the Bagendung Final Waste Processing Site (TPSA) in Cilegon City, as it lacks a landfill facility following the territorial division between Serang Regency and Serang City.

After the Serang Regency Regent's Regulation No. 93 of 2017 issuance, Serang Regency Regent's Regulation No. 21 of 2021 was enacted to amend the former regulation. The amendment pertains to delegating authority from the Regent to District Heads for waste management within Serang Regency. As a result, 15 districts have been granted delegated authority and allocated budgets, personnel, and infrastructure, such as vehicles (Table 3), to facilitate waste management within their respective jurisdictional areas.

Table 2. Waste management facilities.

No	Location	Unit	Info
1	Anyer District: Grogol Indal Village	1	TPS3R
2	Ciruas District: Pelawad Village	1	TPS3R
3	Bojonegara District: Margagiri Village	1	TPS3R
4	Kibin District: Ciagel Village	1	TPS3R
5	Kibin District: Kibin Village	1	TPS3R

Table 3. Waste vehicle in Serang Regency.

No	Institution	Number of Vehicles		
		Dump truck	Arm roll	Cator
1	Environmental Agency	12	12	7
2	Anyer District	2	1	2
3	Cinangka District	2	1	3
4	Kramatwatu District	2	3	6
5	Ciruas District	2	2	4
6	Kibin District	4	1	4
7	Kragilan District	3	1	5
8	Cikande District	2	5	0
9	Pontang District	1	1	2
10	Baros District	1	1	3
11	Waringin Kurung District	1	1	2
12	Padarincang District	1	1	2
13	Ciomas District	1	1	2
14	Pabuaran District	1	1	2
15	Tanara District	1	1	2
16	Tirtayasa District	1	1	2
	Total	**37**	**34**	**48**

The waste management budget allocated to the Environmental Agency of Serang Regency is utilized for various expenditures, including labor costs, vehicle maintenance, fuel, and waste processing fees (tipping fees) at the TPSA Bagendung facility in Cilegon City. Additionally, the budget supports waste management operations at the Kibin TPST, public outreach and education initiatives, the development of waste banks, and the monitoring of waste management activities.

Serang Regency itself also issues regulations and policies related to waste management. These regulations include, among others:

a. Serang Regency waste management master plan 2014.

b. Serang Regency Regional Regulation number 3 of 2019 concerning waste management.

c. Serang Regent Regulation number 6 of 2021 concerning regional policies and strategies in managing household waste and similar types of household waste.

d. Serang Regent's Regulation number 21 of 2021 concerning Amendments to Serang Regent's Regulation number 93 of 2017 concerning Delegation of Part of the Regent's Authority to the District Head regarding waste management in Serang Regency.

e. Regent's Circular Letter Number 3 of 2024, dated January 29, 2024, concerning Village Waste Management.

Community participation in Serang Regency encompasses two main forms: contributing to cleaning fees and engaging directly in waste management through local waste banks. Despite these efforts, the level of community involvement requires significant improvement. Of the 326 villages in Serang Regency, only approximately 43 waste bank units have been established. Table 4 is a comprehensive list of waste banks operating in Serang Regency.

Table 4. Waste banks in Serang Regency.

No	Waste Banks	Districts
1	Ratu Lestari	Cikuesal
2	Mawar Putih	Gunung Sari
3	Mangga	Gunung Sari
4	Berkah bhayangkara	Kramatwatu
5	Cahaya Wali	Carenang

6	Mawar Desa	Tirtayasa
7	Cikande Permai RW 9	Cikande
8	BS Pamarayan	Pamarayan
9	Bersih Berseri Sejahtera	Pabuaran
10	Sambilawang	Waringin Kurung
11	Sadanta	Cikeusal
12	Gupi Mandiri	Anyar
13	SDIT Bina Insani Clean	Waringin Kurung
14	Cikande Permai RW 2	Cikande
15	Nuansa Tani	Kibin
16	Anugrah Ciagel TPS3R Kibin	Kibin
17	Gardenia	Ciruas
18	Cinta Alam	Waringin Kurung
19	SMA 1 Petir	Petir
20	SMA 1 Gunung Sari	Gunung Sari
21	Sukamanah	Baros
22	Sukaindah	Baros
23	SukaCai	Baros
24	Taman Krakatau	Waringin Kurung
25	Mawar Desa	Pontang
26	Anggrek	Pamarayan
27	Power In Ranger	Pulo Ampel
28	Resik Jelinger	Pulo Ampel
29	Greenland	Kramatwatu
30	Flamboyan	Ciruas
31	Gemas	Ciruas
32	Panyaripan	Baros
33	Bina Insani II Clean	Waringin Kurung
34	Cerita Harjatani	Kramatwatu
35	Lestari Liga	Kramatwatu
36	Sabar Subur	Kramatwatu
37	Semut Merah	Kramatwatu
38	KPS TPSSP	Anyar
39	Paku	Anyar
40	Pangandaran	Anyar
41	Gudang Arang	Anyar
42	ASA	Cikande
43	Kareo Mandiri	Jawilan

Factor Analysis of Waste Management

The factor analysis conducted in this study utilized scores derived from responses to 35 statements distributed among 375 participants. These 35 statements were categorized into five distinct variables: (1) technical operations, (2) organization, (3) financing, (4) laws and regulations, and (5) community participation. The factor analysis was performed on the scores obtained from the 375 respondents for each of the 35 statements. Before the analysis, the data underwent validity and reliability testing, excluding five statements from the initial 40.

The initial stage of the analysis involves evaluating the output of the KMO table and Bartlett's Test to assess the suitability of variables for factor analysis using SPSS. This process relies on the Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO MSA) values. If the KMO MSA value exceeds 0.50, it indicates that factor analysis can proceed. SPSS version 16 is employed for the factor analysis related to waste management. The following Table 5 shows the results of the KMO test and Bartlett's Test.

Table 5. KMO table and Bartlett's Test to test the suitability of variables.

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.668
Bartlett's Test of Sphericity	Approx. of Chi-Square	585.002
	df	10
	Sig.	.000

Based on the results presented, the KMO Measure of Sampling Adequacy (MSA) value is 0.668, which exceeds the minimum threshold of 0.50 (0.668 > 0.50). Additionally, Bartlett's Test of Sphericity yielded a significance value (p-value) of 0.000, which is below the accepted threshold of 0.05. These findings confirm that the necessary prerequisites for conducting factor analysis in the study of waste management in Serang Regency have been satisfied, allowing the analysis to proceed.

The second stage involves examining the output of the Anti-image Matrices table (Table 6). This step aims to identify feasible and appropriate variables for inclusion in the subsequent factor analysis process.

Table 6. "Anti-Image Matrices," determines feasible research variables.

Anti-image Matrices		Operational Technical	Organization	Financing	Law and Regulations	Community Participation
Anti-image Covariance	Operational Technical	.547	-.275	.014	-.113	.019
	Organization	-.275	.489	-.030	-.186	.002
	Financing	.014	-.030	.618	-.039	-.349
	Law and Regulations	-.113	-.186	-.039	.608	-.112
	Community Participation	.019	.002	-.349	-.112	.599
Anti-image Correlation	Operational Technical	.683a	-.531	.024	-.196	.033
	Organization	-.531	.670a	-.054	-.342	.003
	Financing	.024	-.054	.596a	-.063	-.574
	Law and Regulations	-.196	-.342	-.063	.790a	-.186
	Community Participation	.033	.003	-.574	-.186	.590a

a. Measures of Sampling Adequacy (MSA)

The letter code (a) in the table denotes the Measures of Sampling Adequacy (MSA) value. The MSA values obtained from the table are as follows:

1. Operational Technical 0.683
2. Organization 0.670
3. Financing 0.596
4. Laws and Regulations 0.790
5. Community Participation 0.590

A second crucial requirement for factor analysis is a Measure of Sampling Adequacy (MSA) value exceeding 0.50 for all variables. The results indicate that all variables in this study meet this criterion, thus enabling the continuation of the analysis. The third stage involves examining the Communalities Table (Table 7) to assess the extent to which the variables can be explained by the underlying factors.

Table 7. Communalities grouping factor suitability based on extraction values.

Communalities		
	Initial	**Extraction**
Operational Technical	1.000	.759
Organization	1.000	.787
Financing	1.000	.791

Extraction Method: Principal Component Analysis.

Communalities		
	Initial	**Extraction**
Law and Regulations	1.000	.651
Community Participation	1.000	.802

Extraction Method: Principal Component Analysis.

As indicated in the communalities table, all variables exhibited an extraction value exceeding 0.50. This threshold value of 0.50 is considered a benchmark for a variable's ability to explain related factors. Given these results, it can be concluded that the variables employed in this research on waste management factors in the Serang Regency are suitable for explaining the underlying factors.

The fourth stage involved analyzing the explained variance for each variable, as detailed in the Total Variance Explained table below.

Table 8. Total variance explained.

Total Variance Explained						
Component	Initial Eingenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.433	48.565	48.565	2.433	48.565	48.565
2	1.358	27.166	74.822	1.358	27.166	74.822
3	.496	9.921	85.743			
4	.383	7.661	93.405			
5	.330	6.595	100.000			

Extraction Method: Principal Component Analysis

Table 8 presents the variable values subjected to factor analysis. This waste management factor analysis involves five variables, corresponding to five components. Two types of analysis were conducted: Initial Eigenvalues and Extraction Sums of Squared Loadings.

Initial Eigenvalues analysis identifies the factors formed in the process. When summed, all factors equal the total number of variables (2.433 + 1.358 + 0.496 + 0.383 + 0.330 = 5). A factor is considered significant if its Initial Eigenvalue exceeds 1. Based on the table, only components 1 (2.433) and 2 (1.358) meet this criterion. Therefore, only these two components can be used to explain the observed variation form.

Based on the Extraction Sums of Squared Loadings values, Component 1 accounts for 48.656% of the total variance, while Component 2 explains 27.166%, resulting in a combined total variance of 75.822%. Consequently, only two factors were identified in this study.

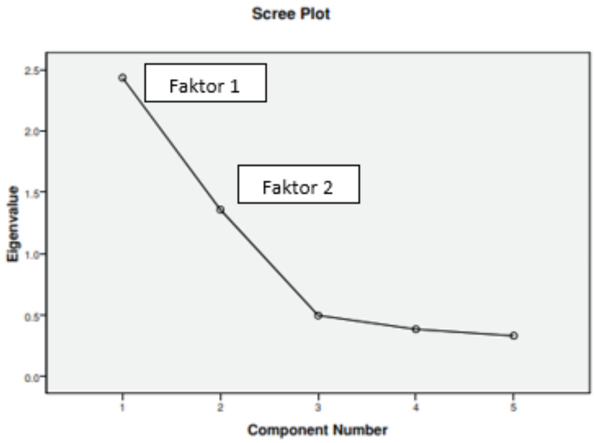

Figure 2. Scree plot shows the number of factors formed.

The scree plot indicates that only two components have Eigenvalues greater than 1 (>1) (Figure 2). Consequently, this research identifies two principal factors in waste management within Serang Regency. The subsequent phase involves analyzing the correlation or relationships between the variables—operational techniques, organizational structure, financing, legal frameworks, and community participation—and the identified factors.

The relationship between these variables can be shown in the component matrix table and rotated component matrix table.

Table 9. Correlation of each variable with the two components formed through the component matrix.

Component Matrix$_a$		
	Component	
	1	**2**
Operational Technical	.725	-.483
Organization	.792	-.400
Financing	.560	.691
Law and Regulations	.794	-.146
Community Participation	.579	.683

Extraction Method: Principal Component Analysis

a. 2 components extracted.

Table 9 presents the strength of the relationship between each variable and the two components constituting the factor. Subsequently, we will conduct a detailed analysis of the grouping of variables into components or factors as defined by the Rotated Component Matrix.

Table 10. The magnitude of the correlation between variables with the components forming Factor 1 and Factor 2.

Rotated Component Matrix$_a$		
	Component	
	1	2
Operational Technical	.871	-.014
Organization	.883	.092
Financing	.098	.884
Law and Regulations	.747	.306
Community Participation	.118	.888

Extraction Method: Principal Component Analysis
Rotation Method: Varimax with Kaiser Normalization
a. Rotation converged in 3 iterations

To ensure that a variable falls into which category or group of factors, it can be done by analyzing the value of the largest correlation between the variable and the factor (component) formed. Table 10 can explain as follows:

1. Operational Technical Variables. The numerical value of the variable correlation with Factor (Component) 1 = 0.871 and Factor (Component) 2 = 0.014. The correlation value of factor 1 is > that of factor 2, so the Operational Technical variable is included in the Factor 1 group;
2. Organizational Variables. The numerical value of the variable correlation with Factor (Component) 1 = 0.883 and Factor (Component) 2 = 0.092. The correlation number value for factor 1 > than factor 2 means that the Organization variable belongs to the Factor 1 group;
3. Financing Variables. The value of the variable correlation number for Factor (Component) 1 = 0.098 and Factor (Component) 2 = 0.884. The value of the correlation number for factor 2 > that of factor 1 can be categorized as a Financing variable belonging to the Factor 2 group;
4. Legal and Regulatory Variables. The value of the variable correlation number with Factor (Component) 1 = 0.747 and Factor (Component) 2 = 0.306. The correlation value of factor 1 is > that of factor 2, so the Law and Regulation variable is included in the Factor 1 group;
5. Community Participation Variables. The value of the variable correlation number for Factor (Component) 1 = 0.118 and Factor (Component) 2 = 0.888. The correlation value of factor 2 is > that of factor 1, indicating that the Community Participation variable is included in the Factor 2 group;

Table 11. Factors and variables.

Factors	Variables
1	Operational variables Organizational Law and regulations
2	Financing Community Participation

Based on the factor analysis calculation pattern using SPSS above (Table 11), determining waste management in Serang Regency can be considered as the main factors: operational technical, organizational, legal, and regulatory variables. Meanwhile, what is included in factor 2 is financing and community participation.

The final step is to calculate the transformation matrix to show that the two factors can explain existing variables such as technical operational waste, financing/funding, laws and regulations, organization/institution, and community participation. The following is a matrix transformation table resulting from SPSS analysis (Table 12).

Table 12. Transformation matrix.

Component Transformation Matrix		
Com	1	2
1	.841	.541
2	-.541	.841

Extraction Method: Principal Component Analysis
Rotation Method: Varimax with Kaiser Normalization

The component transformation matrix shows that Component 1's correlation value is 0.841 > 0.5, and Component 2's correlation is 0.541 > 0.5. This means that the two factors produced can be concluded as suitable for summarizing the five waste management variables analyzed

METHODS

Typology of Waste Management in Serang Regency

Based on the findings from interviews and observations, Serang Regency employs a distinct waste management policy governed by Serang Regent Regulation No. 21 of 2021, which amends Serang Regent Regulation No. 93 of 2017. This regulation delegates a portion of the Regent's authority to district heads concerning regional waste management. Additionally, the presence of Waste Storage Sites (TPS) at multiple locations highlights the adoption of a communal waste management system in Serang Regency (Hendra, 2016). The absence of Transfer

Depots or Intermediate Transit Stations indicates that waste under this communal system is transported directly to the Final Processing Facility.

Waste management initiatives in Serang Regency are categorized into two primary strategies: waste reduction and waste treatment. Waste reduction efforts are implemented through TPS3R and Waste Bank programs. Meanwhile, waste treatment is conducted at TPST facilities utilizing methods like incineration and Refuse-Derived Fuel (RDF) processing and waste management at the final disposal site (TPA) (Figure 3). The results of the study by Fauziah et al. (2023) shows that ash and water content can reduce the calorific value of RDF mixed with paper and garden waste.

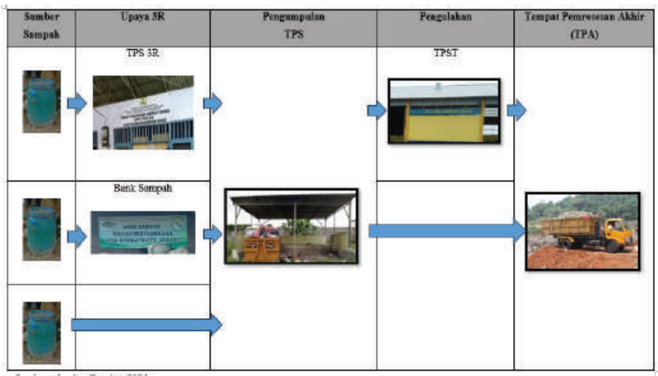

Figure 3. Typology of waste management in Serang Regency.

Factor Analysis of Waste Management in Serang Regency

Based on the results of factorial analysis conducted using SPSS, two key factors influencing waste management in Serang Regency were identified: Factor 1 and Factor 2. Factor 1 encompasses variables related to operational techniques, organizational aspects, and legal and regulatory frameworks. Factor 2 comprises variables related to financing and community participation. Among these, the operational technical variable demonstrated a high correlation of 0.871, indicating a strong association with effective waste management performance in Serang Regency. According to SNI 19-2454-2002 (2002) operational techniques for waste management include:

1) Service Area;
2) Service Level;
3) Technical Operations from container system, storage/collection pattern, transfer/transfer of waste, waste transportation system, waste sorting and processing, and final waste processing.

Service areas are designated as priority zones for waste management. According to Farid (2016), the prioritization of service areas and levels should consider key regions such as main or protocol areas, city centers, commercial districts, and areas marked for development under the RTRW framework. Additionally, the population density of existing settlements is crucial in determining service priorities.

According to planning, waste storage can be done individually or collectively/communally. According to Nafurbenan (2022), containerization can be carried out according to the type or characteristics of waste, such as:

1) Organic waste containers for storing waste such as vegetable scraps, food scraps, fruit scraps, and leaves can use dark containers;
2) Inorganic waste containers accommodate waste such as paper, cardboard, metal, bottles, glass, and other plastics. This trash container can use bright colors.

Meanwhile, according to Nafurbenan (2022), waste collection will consist of 2 types: waste collection to be taken directly to the Final Processing Site (TPA) and waste collection for processing and recycling on a household scale. The types of waste collection/storage consist of several patterns as follows:

1) Indirect Individual Pattern is usually carried out from house to house.
2) Direct individual pattern using trucks usually used for road waste and public facilities.
3) The direct communal pattern is usually applied to waste from markets and commercial areas.
4) Indirect communal patterns are often used for residential or dense housing.

The waste processing and recycling process at TPS, better known as TPS3R, can be done by composting small-scale organic waste and collecting inorganic waste for recycling. 3R waste management can also be carried out by forming a Waste Bank group.

The transfer or transfer of waste can be carried out at collection locations or integrated TPS if the distance between the TPS and TPA is very far, so effective and efficient transportation time is required. Waste processing, according to SNI 19-2454-2002 (2002), is carried out using several processing techniques:

1) Making compost
2) Environmentally friendly incineration/burning of waste
3) Recycle waste
4) Reducing the volume of waste through chopping and pressing/compaction processes
5) Biogasification (Utilization of energy from processing waste)

Utilizing waste as an alternative mixed fuel through Refuse Derived Fuel (RDF) is one way to overcome the waste problem. One type of waste process that can produce RDF products is biodrying. According to Cherul, 2020, biodrying is one part of Mechanical-Biological Treatment (MBT) technology that aims to reduce humidity or water content in waste through the use of heat produced from the activity of microorganisms in degrading organic material so that it is hoped that it can increase the calorific value. According to Chaerul & Wardhani (2020), biodrying takes 7 to 15 days.

The final waste processing is the main facility needed in technical and operational waste management, as the estuary of waste processing. According to Ginting et al. (2018), there are two types of environmentally friendly final processing sites: Sanitary Landfill and Controlled Landfill. Sanitary Landfill is a mechanism for final waste processing through piling and compacting, then covering it with soil as the top layer of cover. This process is continuous and carried out according to the established plan. Covering the waste with covering soil is carried out daily towards the end of operations.

Meanwhile, a controlled Landfill is an open dumping system or increased waste accumulation. Controlled Landfill is a transitional final processing system between open dumping and sanitary landfill processes. Waste is closed in controlled landfills using a layer of soil after the Landfill is full of solidified waste or after a certain period. In other words, the covering of land in this process is not carried out daily but over a longer period.

The current emergency status for waste in the Serang Regency is because the Serang Regency Government does not have a final processing site (TPA). Since the formation of the City of Serang, the Cilowong TPA facility has changed ownership to become the property of the Serang City Government. In 2022, the people of Serang City will reject waste processing at the Cilowong TPA. Furthermore, the Serang Regency Government is collaborating with the Bagendung TPA, Cilegon City, until January 2024, the people of Cilegon City also refuse. Serang Regency is in a waste emergency status and is having difficulty disposing of waste at the Landfill.

The current condition of Serang Regency is in line with the results of Waste Management Factor Analysis research, which shows that the main determinant factor in waste management is the operational technical factor. In this case, the absence of a final processing site in Serang Regency causes waste performance to be hampered and cannot be appropriately implemented.

The following variable influencing Factor 1 is the Organizational Variable with a component value of 0.883. Organizational or institutional variables in waste performance also play a vital role because these organizations or institutions regulate and implement instruments in the operational technicalities of waste management. According to the Ditjen Ciptakarya (2023), the criteria for institutional or organizational aspects are as follows:

1) Institutions must be separate between regulators and implementers in waste management; for example, the Environmental Agency forms a Technical Implementation Unit, or BLUD acts as a waste management operator, while DLH acts as the regulator.
2) Many personnel and good-quality human resources must support the waste organizational structure. This is important considering that cleaning Staff must also follow technological developments in waste management.
3) The organizational structure must be clear, and there are divisions of duties and authority, including the authority to collect levies.

In Serang Regency, the organization authorized to carry out waste management is the District Environmental Agency, which has 1 Waste Management UPTD as a waste management operator. The Serang Regent also has a policy following Serang Regent Regulation number 21 of 2021 that the Serang Regent delegates some of the authority to handle waste to the sub-district head. This is done because Serang Regency has a reasonably large area with 29 sub-districts, so if everything is centralized to the Waste Management UPTD, it will take longer to handle the waste. Apart from that, the sub-district can also determine which priority points require more waste handling. Delegation is currently being carried out to 15 sub-districts.

Based on the research of Puspasari & Mussadun (2017) regarding the role of institutions in waste management in Trenggalek Regency, institutions play an essential role in increasing public awareness, developing waste technology, utilizing waste, ensuring the availability of waste facilities and facilities, and facilitating waste management in Trenggalek Regency. The role of government is 35.54%, the highest compared to the role of society, NGOs, and the private sector.

Variable three strongly influences Factor 1, formed by the Law and Regulation variable. As a legal umbrella in Indonesia, the government has issued Law no. 18 of 2008 concerning Waste Management. Ditjen Ciptakarya (2023) stated that the laws and regulations expected in waste management are as follows:

1) Regional governments have regional regulations, which consist of regional regulations on the establishment of institutions/institutions, regional regulations on provisions related to waste management strategies, and regional regulations on cleanliness levies where the material of the regional regulations must cover the whole, have firmness and can be implemented for the long term;
2) The implementation of these regulations needs to begin with socialization and implementation trials. Apart from that, there is also a need for readiness from law enforcers to anticipate violations;
3) Monitoring and evaluation of the Regulations must be done periodically to test their suitability and feasibility.

The legal and regulatory aspects of waste management have been implemented, starting from the Regional Regulation related to the structure of the Environmental Agency, the Regional Regulation on Waste Management, and the Regional Regulation on Retribution for Cleaning Services. This also includes a Regent's Regulation regarding Regional Policies and Strategies in Waste Management and a Regent's Regulation regarding delegating some authority to the sub-district head in handling waste. The Regent of Serang also issued a circular so the Village Government can play a role in waste management by using village funds.

Wahongan & Pontoh (2022) explained that the presence of Waste Management legislation is necessary for:

1) As a step in the context of harmonizing environmental law to support sustainable development;
2) As a way to control environmental impacts;
3) As a way of structuring and enforcing the law;
4) Increase the capacity and ability of organizations and human resources; and
5) Increasing active awareness of the community so that they care and play a role in managing the environment.

The variables that correlate with Factor 2 are the Financing variable and the Community Participation variable. The Financing variable has a matrix component value of 0.884, while Community Participation is 0.888. Financing variables related to waste management, according to the Director General of Human Settlements, include:

1) Adequate investment according to the needs of facilities and facilities, human resource capacity, socialization, counseling and education in the waste sector.
2) Waste operational costs and maintenance of waste utilities.
3) Waste levy rates are prepared based on regional capabilities and community capabilities.
4) Implementation of incentives and disincentives for communities involved in waste management.
5) Income derived from levies must be reinvested for waste management purposes.

According to Febyanti et al. (2021), forms of active community participation and concern for waste management include:

1) Caring for and keeping the environment clean;
2) Active in reduction activities such as waste banking, collection and processing at source, sorting, transporting, and processing waste; and
3) Providing input, suggestions, proposals, and opinions in improving waste management.

CONCLUSION

Based on this research can be concluded as follows:

1. The typology of waste management in Serang Regency is the direct communal waste collection type. This can be seen from the delegation of authority to the sub-district head, indicating that the type of communal management is regionally appropriate. Meanwhile, it is said to be directly communal because direct transportation is carried out from each Waste Storage Site (TPS) directly to the Final Processing Site without any waste transfer.
2. The factor analysis results on waste management performance in Serang Regency produced two determining factors—factor 1 with component variables: Operational Technical, Organizational, Legal, and Regulatory. Meanwhile, the factor 2 component variables are Financing and Community Participation. Based on the analysis that has been carried out using SPSS and the analysis carried out, it can be stated that these two factors are suitable to be used as a policy combination to improve waste management performance in Serang Regency.

ACKNOWLEDGEMENTS

The author (CH) would like to thank all colleagues at the Environmental Agency of Serang Regency, especially the Head of the Environmental Agency, as well as Mr. Aris Habibi and the staff of Waste Management Section, for their generous support provided. Furthermore, we would like to thank the Waste Bank Group in Serang Regency for their attention and enthusiasm.

REFERENCES

Anshari, S., Listyarini, S., & Nurmawati, S.(2023). Relationship between adaptation and mitigation of climate change with the climate village program (ProKlim) In Paser Regency. *Indonesian Journal of Applied Environmental Studies, 4(2): 93-100*. DOI: 10.33751/injast.v4i2.8957

BPS Kabupaten Serang. (2021). *Kabupaten Serang dalam angka 2021*. Serang: CV. Savaro.

Chaerul, M., & Wardhani, A.K. (2020). Refuse Derived Fuel (RDF) dari Sampah Perkotaan dengan Proses Biodrying: Review. Jurnal Presipitasi: *Media Komunikasi dan Pengembangan Teknik Lingkungan, 17(1): 62-74*. https://doi.org/10.14710/presipitasi.v17i1.62-74

Damanhuri, E., & Padmi, T. (2011). Pengelolaan Sampah. Bandung: Program Studi Teknik Lingkungan Fakultas Teknik Sipil dan Lingkungan ITB.

Ditjen Ciptakarya (2023). Bimbingan Teknis Operasi dan Pemeliharaan Prasarana dan Sarana Persampahan. Jakarta: Kementerian Pekerjaan Umum dan Perumahan Rakyat.

DLH Kabupaten Serang. (2021). *Kebijakan dan Strategi Daerah (Jakstrada) Kabupaten Serang*. Serang: Dinas Lingkungan Hidup Kabupaten Serang.

Faqi, E.A., & Wibawa, L.A.(2023). Investigating the relationship between population growth and temperature change in Nabire and Paniai Regencies. *Indonesian Journal of Applied Environmental Studies, 4(2): 107-110*. DOI: 10.33751/injast.v4i2.9115

Farid, S., & Purba, A. (2020). Perencanaan Pengembangan Aspek Teknis Operasional Dan Finansial Pengelolaan Sampah Kabupaten Mesuji. *Jurnal Profesi Insinyur, 1(2): 1-12*. DOI: https://doi.org/10.23960/jpi.v1n2.45

Fauziah, E.N., Sari, M.M., Suryawan, I.W.K. (2023). Possibility of municipal waste management with Refuse-Derived Fuel (RDF) mixed paper and garden in Depok City. *Indonesian Journal of Applied Environmental Studies, 4(1): 33-38*. DOI: 10.33751/injast.v4i1.7171

Febyanti, P.E., Murniasih, A.A.A., & Suarsana, I.N. (2021). Peran Masyarakat Terhadap Tempat Olah Sampah Setempat (TOSS) di Desa Paksebali. Sunari Penjor: *Journal of Anthropology, 5(2): 54-61*. DOI: https://doi.org/10.24843/SP.2021.v5.i02.p01

Ginting, N., Siahaan, J., & Tarigan, A.P. (2018). Design of concrete waste basin in Integrated Temporarily Sanitary Landfill (ITSL) in Siosar, Karo Regency, Indonesia on supporting clean environment and sustainable fertilizers for farmers. IOP Conf. Ser.: Earth Environ. Sci. 126 012138

Hendra, Y. (2016). Perbandingan Sistem Pengelolaan Sampah di Indonesia dan Korea Selatan: Kajian 5 Aspek Pengelolaan Sampah. *Aspirasi: Jurnal Masalah-Masalah Sosial, 7(1): 77-91*.

Monk, K.A., & Priatna, D. (2022). Environmental security and resilience Indonesia and global challenges. Journal *Indonesian Journal of Applied Environmental Studies, 3(1): 5-11*. DOI: 10.33751/injast.v3i1.5215

Nafurbenan, O. (2022). *Penanganan dan Pengelolaan Sampah*. Makasar: Chakti Pustaka Indonesia.

Priatna, D. & Monk, K.A. (2021). Think Globally, Act Locally publishing amidst global summits. *Indonesian Journal of Applied Environmental Studies, 2(2): 72-77*. DOI: 10.33751/injast.v2i2.4242

Priatna, D., & Khan, S.M. (2024). The importance of education and role of educational institutions in climate change mitigation and achieving UN SDG 13 “Climate Action”. *Indonesian Journal of Applied Environmental Studies, 5(1):1-5*. DOI: 10.33751/injast.v5i1.10559

Priatna, D., & Monk, K.A. (2023). Climate change and its implications on wildlife conservation. *Indonesian Journal of Applied Environmental Studies, 4(2): 64-66*. DOI: 10.33751/injast.v4i2.9661

Puspasari, G.R., & Mussadun, M. (2017). Peran Kelembagaan Dalam Pengelolaan Persampahan di Kabupaten Trenggalek. *Jurnal Pembangunan Wilayah dan Kota, 12(4): 385-399*. https://doi.org/10.14710/pwk.v12i4.13505

Rachmawati, A., Priatna, D., & Rosadi, R. (2024). Evaluation of the Cipalabuan River's water quality and measures for reducing water pollution in the Sukabumi Regency. *Indonesian Journal of Applied Environmental Studies, 5(1): 20-24*. DOI: 10.33751/injast.v5i1.8203

Rizal, M. (2011). Analis pengelolaan sampah perkortaan (Sudi kasus pada Kelurahan Boya Kecamatan Banawa Kabupaten Donggala). *Jurnal SMARTek, 9(2): 155 - 172*.

Rizal, N. M. (2021). *Tata Kelola Persampahan di Indonesia*. Jakarta: Kementerian Lingkungan Hidup dan Kehutanan.

SNI 10-3983-1995. (1995). *Spesifkasi Timbulan Sampah Kata Sedang dan Kata Kecil*. Jakarta: Badan Standarisasi Nasional.

SNI 19-2454-2002 (2002): *Tata Cara Teknik Operasional Pengelolaan Sampah Perkotaan*. Jakarta: Badan Standarisasi Nasional.

Sudirman, F.A., & Phradiansah, P. (2019). Tinjauan Implementasi Pembangunan Berkelanjutan: Pengelolaan Sampah Kota Kendari. *Jurnal Sosial Politik, 5(2): 291-305*. DOI: https://doi.org/10.22219/sospol.v5i2.9821

Sudirman, R. (2018). *Pedoman Pengelolaan Sampah Skala Rumah Tangga*. Jakarta : Kementerian Lingkungan Hidup dan Kehutanan.

Triani, E. (2017). Optimalisasi Kinerja Pengelolaan Sampah di Kota Palangkaraya [Thesis]. Institut Teknologi Sepuluh Nopember (ITS), Surabaya.

Wahongan, A.S., & Pontoh, K.C. (2022). Urgensi Hukum terhadap Sistem Pengelolaan Sampah di Kota Manado. *Tumou Tou Law Review, 1(1): 48-57*.

Wardhani, A.C.K., Retnowati, R., & Istiadi, Y. (2024). Carbon dioxide (CO2) emissions and mitigation efforts based on Bogor City's green open space. *Indonesian Journal of Applied Environmental Studies, 5(2): 92-96*. DOI: 10.33751/injast.v5i2.8513

Xiao, L., Zhang, G., Zhu, Y., & Lin, T. (2017), Promoting public participation in household waste management: A survey based method and case study in Xiamen city, China. *Journal of Cleaner Production, 144: 313-322*.

Yuswandi, Y., Priatna, D., & Rosadi, R. (2024). Cimandiri Watershed, Sukabumi District: A dynamic model for optimizing water resources. *Indonesian Journal of Applied Environmental Studies, 5(2): 84-91*. DOI: 10.33751/injast.v5i2.9811

InJAST
Volume 5, Number 2, October 2024
Pages: 109-117

P - ISSN: 2722 - 0133
E - ISSN: 2722 - 0141
DOI: 10.33751/injast.v5i2.10872

The role of university students in protecting the environment

NAJMALDIN EZALDIN HASSAN*

College of Engineering, Civil and Environment Department, University of Zakho, Kurdistan Region, Iraq

*Corresponding author: *najmaldin.hassan@uoz.edu.krd*

Submitted 23 October 2024; Accepted 28 December 2024

ABSTRACT

The global environmental crisis, characterized by challenges such as climate change, deforestation, pollution, and biodiversity loss, requires urgent action. As an educated and socially aware demographic, university students are uniquely positioned to contribute significantly to environmental protection and sustainability. This paper explores the multifaceted role of university students in addressing environmental issues through education, advocacy, research, and sustainable campus initiatives. It highlights how student-led movements, such as Fridays for Future, have propelled environmental awareness into public discourse and influenced institutional and policy changes. Students' involvement in research and innovation, particularly in renewable energy, sustainable agriculture, and waste management, has led to groundbreaking solutions to mitigate environmental degradation. On university campuses, students drive sustainability through initiatives to reduce waste, conserve energy, and promote biodiversity. Their advocacy extends beyond campuses to regional, national, and international platforms, where they actively shape environmental policies and push for ambitious climate action. Despite challenges such as limited funding and institutional resistance, university students continue to overcome barriers by leveraging academic resources and collaborating with external organizations. Ultimately, university students play a pivotal role in fostering long-term environmental stewardship and promoting sustainable development at both local and global levels.

ABSTRAK

Krisis lingkungan hidup global, yang ditandai dengan tantangan seperti perubahan iklim, penggundulan hutan, polusi, dan hilangnya keanekaragaman hayati, memerlukan tindakan segera. Mahasiswa, sebagai kelompok masyarakat terpelajar dan sadar sosial, mempunyai posisi unik untuk memberikan kontribusi signifikan terhadap perlindungan dan keberlanjutan lingkungan. Makalah ini mengeksplorasi peran beragam mahasiswa dalam mengatasi masalah lingkungan melalui pendidikan, advokasi, penelitian, dan inisiatif kampus berkelanjutan. Laporan ini menyoroti bagaimana gerakan yang dipimpin mahasiswa, seperti Fridays for Future, telah mendorong kesadaran lingkungan ke dalam wacana publik dan mempengaruhi perubahan kelembagaan dan kebijakan. Keterlibatan mahasiswa dalam penelitian dan inovasi, khususnya di bidang energi terbarukan, pertanian berkelanjutan, dan pengelolaan limbah, telah menghasilkan solusi inovatif untuk mengurangi degradasi lingkungan. Di kampus-kampus, mahasiswa mendorong keberlanjutan melalui inisiatif yang bertujuan mengurangi limbah, menghemat energi, dan mempromosikan keanekaragaman hayati. Advokasi mereka melampaui kampus hingga ke platform regional, nasional, dan internasional, di mana mereka secara aktif membentuk kebijakan lingkungan dan mendorong aksi iklim yang ambisius. Meskipun terdapat tantangan seperti terbatasnya pendanaan dan penolakan institusional, mahasiswa terus mengatasi hambatan dengan memanfaatkan sumber daya akademis dan berkolaborasi dengan organisasi eksternal. Pada akhirnya, mahasiswa memainkan peran penting dalam mendorong pengelolaan lingkungan hidup jangka panjang dan mendorong pembangunan berkelanjutan baik di tingkat lokal maupun global.

Keywords: *Environmental advocacy, environmental protection, sustainable campus initiatives, sustainable development, university students*

INTRODUCTION

The global environmental crisis, characterized by challenges such as climate change, deforestation, pollution, and biodiversity loss, demands urgent and sustained action (Priatna & Monk, 2023). As an educated and socially aware demographic, university students are uniquely positioned to contribute significantly to environmental protection efforts. Their active participation in sustainability initiatives is crucial for fostering long-term environmental stewardship, which can produce human health and welfare in the future (Priatna & Monk, 2022). As future leaders, students hold the potential to shape both local and global environmental policies (Shiel et al., 2016; Filho et al., 2019).

University students are well-equipped to address environmental challenges due to their education and social awareness. As members of academic institutions, they have access to extensive resources, including advanced knowledge, cutting-edge technology, and research opportunities, enabling meaningful engagement with environmental issues (Shiel et al., 2016). Their academic experiences equip them with critical thinking and problem-solving skills essential in addressing complex environmental problems.

Moreover, university students belong to a generation that has grown up amid increasing global awareness of environmental concerns, particularly the existential threat of climate change. Priatna & Khan (2024) suggested that educational institutions play a crucial role in achieving the Climate Action of Sustainable Development Goals by fostering knowledge, research, advocacy, and sustainable practices. This demographic is characterized by its willingness to advocate for change, challenge unsustainable practices, and push for policies that prioritize environmental conservation (Filho et al., 2019). As emerging leaders and innovators, students possess the potential to shape both local and global environmental policies, thereby influencing the future of sustainable development.

One of the most significant contributions university students can make is their active involvement in sustainability initiatives. On campuses worldwide, students are participating in grassroots movements that promote environmental awareness, conservation, and sustainable living. These initiatives range from waste reduction campaigns to promoting renewable energy and eco-friendly practices.

Research shows that student-led movements have driven universities toward more sustainable operations. For example, many universities have implemented "Green Campus" initiatives to reduce the institution's carbon footprint, enhance recycling efforts, and promote sustainable food systems. These efforts reduce the environmental impact of academic institutions and serve as models for broader societal change (Shiel et al., 2016).

Furthermore, students engage in policy advocacy both within and outside university settings. Numerous student organizations have successfully campaigned for initiatives such as divestment from fossil fuels, adopting renewable energy technologies on campuses, and integrating environmental studies into academic curricula. Their advocacy frequently extends to national and international arenas, where they play a pivotal role in advancing global environmental movements (Filho et al., 2019).

University students are increasingly becoming active participants in shaping global environmental policies. Through collaboration with non-governmental organizations (NGOs), government agencies, and international bodies, students have made their voices heard on the world stage. Events such as the United Nations Climate Change Conferences (COP) have seen significant youth participation, with university students playing a key role in calling for ambitious climate action (MacKay et al., 2020).

By participating in these platforms, students ensure that the perspectives and concerns of younger generations are integrated into policy discussions. As emerging leaders, their involvement in environmental policy-making is essential for achieving long-term sustainability objectives. Moreover, these experiences equip students with the skills and knowledge necessary for future leadership roles in environmental governance.

LEADERSHIP AND ADVOCACY: THE ROLE OF UNIVERSITY STUDENTS IN ENVIRONMENTAL ACTION

Student-Led Environmental Movements and Advocacy

University students are frequently at the forefront of environmental advocacy, often taking on leadership roles in campaigns promoting environmental awareness and sustainable practices. One of the most prominent examples of student-led environmental activism is the Fridays for Future movement. This global movement, initiated by Greta Thunberg in 2018, encourages students to protest against insufficient action on climate change by skipping classes on Fridays and demanding more ambitious climate policies from governments and institutions. The movement has garnered international attention, with millions of students worldwide participating in climate strikes and rallies (MacKay et al., 2020). Moreover, student unions and organizations can encourage universities to adopt greener policies, including advocating for divestment from fossil fuels, reducing campus carbon footprints, and promoting sustainable waste management systems. Students also lobby to push for regional, national, and international environmental policies (Jain & Pant, 2010).

Student activists involved in Fridays for Future and other movements, such as Extinction Rebellion, have been instrumental in amplifying the urgency of climate change. They highlight the need for systemic change in policies and practices contributing to environmental degradation, including advocating for renewable energy adoption, deforestation prevention, and biodiversity protection. These efforts underscore students' critical role in shaping public discourse on environmental issues and influencing policy decisions.

Advocacy for Institutional Change: University Campuses as Catalysts for Sustainability

University campuses are microcosms of society, where student unions and organizations actively advocate for greener policies. One key area where students are leading change is the push for universities to divest from fossil fuels. Many universities manage large endowments that invest in fossil fuel companies, contributing indirectly to climate change. Student-led campaigns like Fossil Free and Divest Harvard have successfully lobbied universities to shift their investments toward renewable energy sources and other environmentally responsible assets (Ayling & Gunningham, 2017).

In addition to advocating for divestment, students are instrumental in promoting broader sustainability initiatives on campus. These efforts include reducing campus carbon footprints through energy efficiency programs, renewable energy adoption, and sustainable transportation options such as cycling, carpooling, and electric vehicle infrastructure. Students also campaign for waste reduction measures, including enhanced recycling programs, composting, and eliminating single-use plastics. These initiatives contribute to the development of environmentally friendly campus operations, and in many cases, universities have adopted policies as a direct result of student pressure (Jain & Pant, 2010).

Student Involvement in Policy Advocacy at Multiple Levels

Beyond advocating for change at the university level, students also lobby to influence regional, national, and international environmental policies. Many student organizations collaborate with non-governmental organizations (NGOs), government bodies, and international institutions to advocate for sustainable policies and regulations. For example, students participate in conferences such as the United Nations Climate Change Conferences (COP), where they work alongside activists, policymakers, and environmental experts to call for stronger climate action and sustainable development policies (MacKay et al., 2020).

Students also contribute to local and regional sustainability efforts by engaging with city councils, state governments, and other bodies to push for environmental legislation. Their advocacy includes calls for renewable energy mandates, stricter emissions standards, and policies to conserve natural resources. Student delegations have participated in climate negotiations at the international level, providing a voice for younger generations and influencing the global agenda on climate change and environmental protection.

The Impact of Student Leadership on Environmental Policies

University students' leadership and advocacy efforts have yielded tangible results in many instances. Their campaigns have led to policy shifts within universities, such as adopting renewable energy targets, improvements in waste management, and divestment from environmentally harmful industries. Moreover, student activism has brought about greater public awareness of environmental issues, fostering a culture of sustainability in academic settings and beyond (Barth & Rieckmann, 2012).

Research suggests that student leadership in environmental advocacy is critical in shaping long-term sustainability goals. Students' participation in environmental movements helps to challenge existing structures and practices that contribute to environmental degradation, pushing for systemic changes that prioritize sustainability (Filho et al., 2020). Their involvement in policymaking and advocacy efforts ensures that future generations will be better equipped to address the environmental challenges they inherit.

RESEARCH AND INNOVATION

Universities serve as centers of knowledge and innovation, offering students a unique platform to engage in research that addresses environmental issues. University students contribute significantly to breakthroughs such as renewable energy, sustainable agriculture, and waste management technologies. Through academic programs, research projects, and independent initiatives, students actively participate in developing innovative solutions to mitigate environmental degradation.

Student Contributions to Environmental Research

One of the key roles students play in environmental protection is through research. Universities facilitate various research activities, often involving students in projects that tackle critical environmental problems. By engaging in such research, students help to develop new technologies, approaches, and systems that support sustainable development. For example, research in renewable energy has led to advancements in solar panels, wind turbines, and energy storage technologies, significantly reducing greenhouse gas emissions (Filho et al., 2020).

In sustainable agriculture, student research has contributed to developing more efficient irrigation methods, organic farming practices, and crop rotation systems that conserve water and reduce the need for harmful pesticides. Similarly, waste management innovations, including recycling technologies, composting methods, and waste-to-energy processes, have emerged from university research labs where students are critical in testing and refining these systems.

Students also engage in environmental modelling and simulations, using advanced computational techniques to predict the impact of environmental policies and climate change scenarios. These simulations inform real-world applications, such as urban planning for climate resilience, biodiversity conservation, and pollution control strategies (Ferronato et al., 2022).

Research Programs and Opportunities for Students

Many universities offer specialized research programs and academic coursework on sustainability and environmental sciences. These programs allow students to gain the knowledge and skills to address specific environmental challenges. For example, environmental engineering, biology, chemistry, and geography students are often involved in cutting-edge research related to climate science, ecosystem management, and sustainable technologies (Ferronato et al., 2022).

Programs like Sustainability Science or Environmental Studies integrate interdisciplinary approaches to understanding environmental systems and solutions. These courses encourage students to approach environmental issues from multiple perspectives, combining scientific research with social, economic, and political analyses. By participating in these programs, students gain expertise in specialized fields and learn how to apply their knowledge to real-world environmental problems.

Moreover, many universities offer opportunities for students to participate in collaborative research initiatives with government agencies, non-governmental organizations (NGOs), and private sector companies. These collaborations give students access to practical experience and mentorship, preparing them to become leaders in sustainability fields.

Independent Student-Led Research Initiatives

In addition to formal academic programs, many students engage in independent research projects on sustainability and environmental innovation. These projects often arise from a desire to address local or global environmental challenges and may involve working with community organizations or other external stakeholders. For example, students have initiated research on water purification systems for underdeveloped regions, green architecture solutions for urban areas, and renewable energy projects in rural communities (Filho et al., 2020).

Student-led research also plays a role in developing new materials and products that promote sustainability. For example, research into biodegradable materials, alternatives to single-use plastics, and sustainable packaging is often spearheaded by university students driven to reduce pollution and waste. These initiatives contribute to environmental protection and foster an entrepreneurial spirit among students, some of whom go on to create start-up companies based on their research findings.

The Impact of Research on Environmental Policy and Practice

The research conducted by university students often has a broader impact beyond academia, influencing environmental policies and practices. Research findings are frequently presented at conferences, published in academic journals, and used to inform local, national, and international policy decisions. For instance, students' work on renewable energy or waste management can contribute to shaping municipal sustainability plans or national climate strategies (Ferronato et al., 2022).

Moreover, universities often collaborate with governmental agencies to implement student research into actionable policies. For example, a university's research into carbon sequestration methods or climate change mitigation strategies may inform environmental regulations or international climate agreements. By participating in research that has real-world applications, students are directly contributing to global efforts to address environmental crises.

SUSTAINABLE CAMPUS INITIATIVES

As microcosms of society, universities provide a unique opportunity to implement and test sustainable practices that can later be adopted in broader community contexts. Sustainable campus initiatives focus on reducing the environmental impact of universities, and students play a crucial role in advocating for, implementing, and participating in these initiatives. Through active engagement in recycling, energy conservation, and sustainable transportation programs, students contribute to creating environmentally conscious campuses that serve as models for sustainability.

Student Involvement in Green Campus Initiatives

Many universities have established comprehensive sustainability programs that rely heavily on student participation. Students advocate for and implement initiatives to reduce waste, conserve energy, and promote sustainable behaviors across campus. One of the most effective ways students contribute is through recycling programs. Many campuses now have student-led initiatives encouraging waste sorting, composting, and reducing single-use plastics. These programs significantly reduce the environmental footprint of universities by diverting waste from landfills and encouraging a culture of reuse and recycling (Filho et al., 2023).

In addition, students participate in energy conservation efforts, such as promoting energy-efficient lighting, turning off unused electronics, and pushing for adopting renewable energy sources like solar and wind power on campus. Student unions and environmental clubs often lobby universities to invest in sustainable energy technologies, which not only help reduce the institution's carbon footprint but also serve as a demonstration of renewable energy solutions that can be replicated elsewhere.

Water conservation is another area where student initiatives have made a significant impact. Many campuses have implemented programs to reduce water waste by installing low-flow faucets and rainwater harvesting systems and promoting awareness about water conservation. Students frequently lead these efforts, ensuring that sustainability is integral to campus life.

Campus-Wide Green Initiatives and "Green Office" Programs

Many universities have adopted "Green Office" programs to create sustainable workplaces within academic institutions. These offices often function as hubs for environmental awareness, coordinating various sustainability initiatives and relying on student involvement to implement green practices. The Green Office Model, which started in the Netherlands and has been adopted by universities worldwide, focuses on reducing energy consumption, water use, and waste production while fostering a culture of sustainability on campus (Filho et al., 2023).

Students are critical to the success of these Green Office programs, often taking on leadership roles within the initiatives. They help organize campaigns that raise awareness of environmental issues, promote eco-friendly behaviors, and track the institution's sustainability performance. These offices also provide students with hands-on experience in environmental management and sustainability leadership, equipping them with the skills to promote sustainable practices in future workplaces.

Sustainable Transportation Solutions

Sustainable transportation is another area where students contribute to greening campuses. By advocating for cycling infrastructure, promoting public transportation, and encouraging carpooling, students help reduce the environmental impact of commuting. Many universities have implemented bike-sharing programs, electric vehicle charging stations, and incentives for carpooling, with strong support and participation from students.

These efforts help lower carbon emissions from daily commuting and promote healthier, more sustainable lifestyles. Some campuses even offer students free or subsidized public transportation passes, further encouraging the use of environmentally friendly transportation options.

Promoting Biodiversity and Green Spaces on Campus

Students are also involved in projects that enhance biodiversity and promote the creation of green spaces on campuses. Initiatives such as tree planting, establishing campus gardens, and creating wildlife habitats contribute to preserving biodiversity and improving university grounds' aesthetic and ecological value. These projects benefit the environment and provide students with hands-on experience in sustainability and environmental management.

For example, many campuses have designated green spaces where students plant native trees and plants, creating habitats for local wildlife. These spaces serve as outdoor classrooms where students can study ecology and sustainability in a practical setting (Azhar, 2020). Additionally, campus gardens often serve as organic food sources for campus dining services, further promoting sustainability.

The Role of Students in Developing Sustainable Campuses as Models for Society

The sustainability initiatives implemented on university campuses, with the active participation of students, demonstrate how institutions can operate in an environmentally responsible manner. By engaging in these projects, students help create campuses that serve as sustainability models for broader society. Universities that successfully implement green initiatives often share their strategies and successes with other institutions, local governments, and communities, amplifying the impact of their sustainability efforts.

Furthermore, students who participate in campus sustainability projects carry the lessons they learn into their future careers, contributing to the growth of a generation of leaders who prioritize environmental stewardship. Research indicates that sustainable campus initiatives benefit the environment and promote a culture of sustainability that influences behavior both during and after students' academic careers (Filho et al., 2023).

COMMUNITY ENGAGEMENT AND EDUCATION

University students have a crucial responsibility to extend their environmental advocacy beyond the confines of campus life. By engaging with local communities through outreach programs and educational initiatives, students can raise awareness of environmental issues and promote sustainable practices effectively. This section explores how students contribute to community engagement and education in the context of environmental advocacy.

Outreach Programs and Service-Learning Initiatives

Many universities encourage students to participate in service-learning programs combining academic learning with community service. These programs allow students to collaborate with local organizations on eco-friendly projects that address specific environmental challenges. Examples include community gardens, pollution cleanup efforts, and conservation awareness campaigns.

For instance, community gardens promote local food production and foster community cohesion and awareness about sustainable agricultural practices. Students involved in these projects often learn about permaculture, organic farming, and local food systems' benefits while educating community members about sustainable practices (Žalėnienė & Pereira, 2021; Buchan et al., 2007).

Pollution cleanup efforts, such as river or beach cleanups, provide students hands-on experience addressing environmental degradation. Through these activities, students engage residents, raise awareness of pollution issues, and inspire community members to take action to protect their natural surroundings.

Environmental Awareness Campaigns

Students often lead or participate in environmental awareness campaigns to educate the public about sustainability issues. These campaigns can take various forms, including workshops, seminars, and informational booths at local events. For example, students might organize events to discuss the importance of biodiversity, water conservation, or the impacts of climate change on local ecosystems.

Such campaigns can effectively influence public perceptions and behaviors regarding sustainability. Using social media and other communication channels, students can amplify their message and reach a wider audience, fostering a culture of environmental responsibility within the community (Žalėnienė & Pereira, 2021; Buchan et al., 2007).

Peer Education and Promoting Sustainable Behaviors

In addition to outreach efforts, university students can act as peer educators on sustainability issues. This outreach encourages fellow students to adopt environmentally friendly behaviors, such as reducing plastic usage, conserving water, and supporting ethical consumption practices. Peer education is a powerful tool for promoting behavioral change, as students often relate better to their peers than to authority figures (Nousheen et al., 2020).

For example, students might organize campaigns to promote the use of reusable containers and bags, or they may hold workshops on composting and recycling. By creating a supportive environment that fosters sustainable choices, peer educators can influence their peers to adopt habits that contribute to environmental conservation.

The Impact of Student Engagement on Behavioral Change

Research indicates that student engagement in environmental education and outreach can lead to long-lasting behavioral changes among those directly involved and within the broader community (Nousheen et al., 2020). For instance, students participating in sustainability initiatives will likely continue practising environmentally responsible behaviors after graduation. This effect can be amplified as students share their experiences and knowledge with friends, family, and community members.

Furthermore, community engagement projects provide students with practical experience and a deeper understanding of environmental issues' complexities. This hands-on approach enhances their ability to communicate effectively about sustainability, fostering a sense of responsibility beyond their academic studies.

Collaborations with Local Organizations

Many universities forge partnerships with local organizations, nonprofits, and government agencies to enhance community engagement efforts. These collaborations enable students to work on real-world problems while benefiting from the expertise and resources of established organizations. For example, partnerships with environmental NGOs can provide students with access to research data, funding opportunities, and community networks that enhance the effectiveness of their outreach initiatives.

Through these collaborations, students can address pressing environmental issues more effectively and make a tangible impact in their communities. By engaging with local stakeholders, students also learn the importance of inclusive and collaborative approaches to sustainability, which are essential for creating meaningful and lasting change.

CHALLENGES AND OPPORTUNITIES

University students have immense potential to drive environmental change but face several challenges that can hinder their efforts. Limited funding, institutional resistance, and lack of awareness are some obstacles students encounter when trying to implement sustainable practices on campus and beyond. Despite these challenges, students have numerous opportunities to make meaningful contributions to environmental protection. With adequate support from universities and collaborations with external organizations, students can overcome barriers and harness their potential as leaders in sustainability.

Challenges Facing University Students in Environmental Protection

Limited funding and resources

One of the most significant challenges students face working on environmental initiatives is the lack of funding and resources. Environmental projects on campus or in the community often require financial support for materials, technology, and outreach activities. However, universities and student organizations may have limited budgets, making it difficult to implement large-scale or long-term initiatives (Boca & Saraçlı, 2019).

In addition to financial constraints, students may face a shortage of institutional resources, such as access to sustainable infrastructure, faculty mentorship, or research equipment. Without these resources, student-led initiatives may struggle to gain momentum or achieve their desired impact.

Institutional resistance to change

Even when students advocate for sustainable practices on campus, they may encounter resistance from the university administration or other institutional stakeholders. Like any large organization, universities may be slow to adopt new policies or practices, particularly if they require significant investment or represent a departure from established routines (Boca & Saraçlı, 2019). For example, efforts to divest from fossil fuels or to reduce the university's carbon footprint may face opposition due to perceived financial or logistical challenges.

This institutional inertia can be frustrating for students, especially those who are passionate about immediate action to address environmental concerns. In some cases, students may feel that their voices are not heard or valued by decision-makers within the university.

Student disengagement and burnout

Another challenge is the potential for student disengagement, particularly when students feel overwhelmed by the scale of global environmental problems such as climate change, biodiversity loss, and pollution. The complexity and enormity of these issues can lead to feelings of helplessness or burnout, mainly when progress seems slow or insufficient (Boca & Saraçlı, 2019). Students may also struggle to balance their academic responsibilities with their environmental activism, leading to decreased participation in sustainability initiatives.

Opportunities for Overcoming Challenges

University support for student-led initiatives

Despite these challenges, students have numerous opportunities to succeed in their environmental efforts. Universities play a critical role in providing the support needed to overcome barriers. By offering financial assistance, resources, and platforms for student voices, universities can empower students to take action on sustainability. For example, universities can create dedicated sustainability funds or grants to support student-led environmental projects. These funds can finance campus recycling programs, renewable energy installations, or community outreach activities. Additionally, universities can provide resources such as access to research labs, mentorship from faculty members, and spaces for student organizations to meet and collaborate (Filho, 2020).

Moreover, universities can help amplify student voices by including them in decision-making processes related to campus sustainability. By creating sustainability committees or advisory boards that include student representatives, universities can ensure that student perspectives are considered when developing policies or implementing green initiatives.

Collaboration with external organizations

Another opportunity for students is the potential for collaboration with external organizations, such as environmental NGOs, government agencies, and private companies. These partnerships provide students with practical experience and access to larger networks that can support their sustainability efforts. For example, students may collaborate with local environmental organizations to conduct research, implement community-based projects, or advocate for policy changes at the municipal level.

Such collaborations also offer students valuable opportunities to learn from experienced professionals and gain skills that will benefit them in their future careers. In return, external organizations benefit from students' energy, creativity, and fresh perspectives (Filho, 2020).

Leveraging technology and social media

Technology and social media offer additional opportunities for students to overcome funding, awareness, and engagement challenges. Crowdfunding platforms, for instance, allow students to raise money for environmental projects by reaching out to the public for support. Social media can organize campaigns, raise awareness, and mobilize peers for environmental action.

Digital platforms enable students to connect with like-minded individuals and organizations worldwide, creating global networks of sustainability advocates. Through online communities, students can share resources, exchange ideas, and coordinate actions on a larger scale than possible within a single university campus.

The Path Forward: Creating Lasting Impact

To fully harness the opportunities available, universities and students must work together to create environments that encourage and support environmental activism, including reducing institutional barriers, providing adequate funding and resources, and promoting collaborations both within and outside the university. When these conditions are met, students are well-positioned to make a lasting impact on environmental sustainability, both on campus and in the broader world.

Students who engage in sustainability initiatives often carry their experiences and knowledge into their future careers, contributing to developing a generation of leaders who prioritize environmental stewardship. By addressing challenges head-on and leveraging available opportunities, university students can play a vital role in shaping a more sustainable future.

CONCLUSIONS

The active involvement of university students in environmental protection is crucial in addressing the pressing challenges of our time, including climate change, biodiversity loss, and pollution. As a demographic characterized by education, social awareness, and a commitment to sustainability, students are uniquely positioned to drive meaningful change on their campuses and in the broader community.

University students leverage their academic environments to become effective advocates for sustainability. Their participation in grassroots movements, such as Fridays for Future, exemplifies their ability to mobilize support for environmental causes and influence public discourse on critical issues. By advocating for institutional changes, such as divestment from fossil fuels and adopting sustainable practices, students contribute to more environmentally responsible universities and serve as models for societal transformation.

Universities serve as incubators for research and innovation, where students contribute significantly to developing sustainable technologies and practices. Their involvement in research initiatives addressing renewable energy, sustainable agriculture, and waste management demonstrates the potential for student-led projects to generate impactful solutions. The knowledge and skills gained through these experiences prepare students for future leadership roles in environmental governance and sustainability.

Sustainable campus initiatives, driven by student participation, create tangible environmental benefits. From recycling programs to green office initiatives and sustainable transportation solutions, these efforts reduce the ecological footprint of universities and foster a culture of sustainability. By engaging in projects that promote biodiversity and create green spaces, students enhance the ecological value of their campuses while gaining practical experience in environmental stewardship.

As active participants in shaping global environmental policies, university students play a vital role in ensuring that the perspectives and concerns of younger generations are represented in policy discussions. Their involvement in international forums, such as the United Nations Climate Change Conferences, emphasizes youth voices' importance in the climate action dialogue. The experiences students gain through advocacy and collaboration prepare them to become informed leaders capable of addressing complex environmental challenges.

In conclusion, the role of university students in protecting the environment is multifaceted and impactful. By harnessing their education, engaging in advocacy, contributing to research, and implementing sustainable practices on campus, students are addressing immediate environmental concerns and laying the groundwork for a more sustainable future. Their commitment to environmental stewardship ensures that they will continue to influence policies and practices that prioritize the health of our planet for generations to come.

REFERENCES

Ayling, J., & Gunningham, N. (2017). Non-state governance and climate policy: the fossil fuel divestment movement. *Climate Policy, 17(2): 131-149*. https://doi.org/10.1080/14693062.2015.1094729

Azhar, S. N. F. S., Akib, N. A. M., Khelghat-Doost, H., & Sibly, S. (2020). Students as catalysts in achieving sustainable development in higher education: Initiatives and program highlights. *Sustainability: The Journal of Record, 13(6): 271-281*. https://doi.org/10.1089/sus.2019.0038

Barth, M., & Rieckmann, M. (2012). Academic staff development as a catalyst for curriculum change towards education for sustainable development: an output perspective. *Journal of Cleaner Production, 26: 28-36*. https://doi.org/10.1016/j.jclepro.2011.12.011

Boca, G. D., & Saraçlı, S. (2019). Environmental education and student's perception for sustainability. *Sustainability, 11(6): 1553*. https://doi.org/10.3390/su11061553

Buchan, G. D., Spellerberg, I. F., & Blum, W. E. (2007). Education for sustainability: Developing a postgraduate-level subject with an international perspective. *International Journal of Sustainability in Higher Education, 8(1): 4-15*. https://doi.org/10.1108/14676370710717553

Ferronato, N., Pasinetti, R., Valencia Vargas, D., Calle Mendoza, I. J., Guisbert Lizarazu, E. G., Gorritty Portillo, M. A., ... & Torretta, V. (2022). Circular economy, international cooperation, and solid waste management: A development project in La Paz (Bolivia). *Sustainability, 14(3): 1412*. https://doi.org/10.3390/su14031412

Filho, W. L., de Vasconcelos, C. R. P., Ferreira, P., Araújo, M. M., Berenguer, A., Almeida, N., ... & Agostinho, T. L. A. (2023). Perceptions of the academic community on the performance of sustainable development initiatives in higher education. *Sustainable Development, 31(5): 3896-3912*. https://doi.org/10.1002/sd.2633

Filho, W. L., Eustachio, J. H. P. P., Caldana, A. C. F., Will, M., Lange Salvia, A., Rampasso, I. S., ... & Kovaleva, M. (2020). Sustainability leadership in higher education institutions: An overview of challenges. *Sustainability, 12(9): 3761*. https://doi.org/10.3390/su12093761

Filho, W. L., Will, M., Salvia, A. L., Adomßent, M., Grahl, A., & Spira, F. (2019). The role of green and Sustainability Offices in fostering sustainability efforts at higher education institutions. *Journal of Cleaner Production, 232: 1394-1401*. https://doi.org/10.1016/j.jclepro.2019.05.273

Jain, S., & Pant, P. (2010). Environmental management systems for educational institutions: A case study of TERI University, New Delhi. *International Journal of Sustainability in Higher Education, 11(3): 236-249*. https://doi.org/10.1108/14676371011058532

MacKay, M., Parlee, B., & Karsgaard, C. (2020). Youth engagement in climate change action: Case study on indigenous youth at COP24. *Sustainability, 12(16): 6299*. https://doi.org/10.3390/su12166299

Nousheen, A., Zai, S. A. Y., Waseem, M., & Khan, S. A. (2020). Education for sustainable development (ESD): Effects of sustainability education on pre-service teachers' attitude towards sustainable development (SD). *Journal of Cleaner Production, 250: 119537*. https://doi.org/10.1016/j.jclepro.2019.119537

Priatna, D., & Khan, S. M. (2024). The importance of education and role of educational institutions in climate change mitigation and achieving UN SDG 13 "Climate Action". *Indonesian Journal of Applied Environmental Studies, 5(1): 1-5*. 10.33751/injast.v5i1.10559

Priatna, D., & Monk, K. A. (2022). The role of the academic community in combating wildlife trafficking. Indonesian *Journal of Applied Environmental Studies, 3(2): 85-91*. 10.33751/injast.v3i2.6302

Priatna, D., & Monk, K. A. (2023). Climate change and its implications on wildlife conservation. *Indonesian Journal of Applied Environmental Studies, 4(2): 64-66*. 10.33751/injast.v4i2.9661

Shiel, C., Filho, W. L., do Paço, A., & Brandli, L. (2016). Evaluating the engagement of universities in capacity building for sustainable development in local communities. *Evaluation and Program Planning, 54: 123-134*. https://doi.org/10.1016/j.evalprogplan.2015.07.006

Žalėnienė, I., & Pereira, P. (2021). Higher education for sustainability: A global perspective. *Geography and Sustainability, 2(2): 99-106*. https://doi.org/10.1016/j.geosus.2021.05.001

InJAST
Volume 5, Number 2, October 2024
Pages: 118-121

P - ISSN: 2722 - 0133
E - ISSN: 2722 - 0141
DOI: 10.33751/injast.v5i2.11039

Genetic variation based on RAPD (Random Amplified Polymorphic DNA) markers in western tarsiers (*Cephalopachus bancanus*) from South Sumatra and Bangka Island

PUTRI RIZKI PRATIWI, MUHARNI, ARUM SETIAWAN, LAILA HANUM, INDRA YUSTIAN*

Biology Department, Faculty of Mathematics and Natural Sciences, Universitas Sriwijaya QJJW+GFV, Indralaya Indah, Kec. Indralaya, Kabupaten Ogan Ilir, Sumatera Selatan 30862, Indonesia

*Corresponding author: *idr_yustian@unsri.ac.id*

Submitted 5 December 2024; Accepted 30 December 2024

ABSTRACT

The western tarsier (*Cephalopachus bancanus*) is a nocturnal primate classified as Vulnerable by the IUCN. Understanding the genetic variation of tarsier populations in South Sumatra and Bangka Island is crucial for developing effective conservation strategies to protect this unique species. The research aims to determine the genetic variations of tarsiers from South Sumatra and Bangka Island by using 10 primers of the Random Amplified Polymorphic DNA (RAPD) molecular marker, namely ILO 525, ILO 1212, ILO 1204, OPE 16, OPE 17, OPE 19, OPF 06, OPF 04, OPY 03 and OPY 13. The RAPD primers utilized in this study are universal and effectively detect genetic diversity at interspecies and intraspecies levels. These primers have demonstrated the ability to produce clear and distinct electrophoresis band patterns in primates and other mammals. A total of six tissue samples were collected from Bangka Island, specifically from Petaling Village, Mendo Barat, and two additional samples were obtained from South Sumatra, originating from Selangit, Musi Rawas, and Padang Bindu, Ogan Komering Ulu. The Bangka Island samples were derived from a single population inhabiting a secondary forest characterized by shrubs and old rubber plantations. In contrast, the South Sumatra samples were obtained from secondary forest environments. Eight of the ten RAPD primers successfully amplified 89 DNA fragments, exhibiting a high degree of polymorphism. The genetic distance analysis, based on Dice coefficient values ranging from 0.000 to 0.629, revealed varying levels of genetic divergence among the samples. The bootstrap analysis further demonstrated that the relationships among all Western Tarsier (*Cephalopachus bancanus*) samples had a confidence level exceeding 50%. The observed high polymorphism reflects substantial genetic variability among the samples. RAPD markers thus offer a valuable tool for studies focusing on the relationships within closely related populations.

ABSTRAK

Tarsius (*Cephalopachus bancanus*) merupakan primata nokturnal yang berstatus Rentan (Vulnerable) pada IUCN. Informasi mengenai keragaman genetik tarsius asal Sumatera Selatan dan Pulau Bangka sangat diperlukan untuk menerapkan strategi konservasi yang tepat dalam upaya perlindungan primata nokturnal yang menarik ini. Penelitian bertujuan untuk mengetahui keragaman genetik tarsius asal Sumatera Selatan dan Pulau Bangka dengan menggunakan 10 primer penanda molekuler Random Amplified Polymorphic DNA (RAPD) yaitu ILO 525, ILO 1212, ILO 1204, OPE 16, OPE 17, OPE 19, OPF 06, OPF 04, OPY 03 dan OPY 13. Primer RAPD yang digunakan merupakan primer universal yang dapat mengidentifikasi keragaman baik pada tingkat interspesies maupun intraspesies, serta terbukti memiliki visualisasi bentuk pita yang jelas dari hasil elektroforesis pada primata dan mamalia lainnya. Enam sampel jaringan dikumpulkan dari Pulau Bangka (Desa Petaling, Mendo Barat) dan dua sampel dari Sumatera Selatan (dari Selangit, Musi Rawas dan Padang Bindu, Ogan Komering Ulu). Sampel dari Bangka berasal dari populasi yang sama pada tipe habitat yang sama, yaitu hutan sekunder yang berisi semak belukar dan tanaman karet tua. Sementara sampel dari Sumatera Selatan berasal dari hutan sekunder. Delapan dari sepuluh primer RAPD yang digunakan menghasilkan amplifikasi DNA sebanyak 89 fragmen DNA dengan persentase polimorfisme yang tinggi. Hasil analisis nilai jarak genetik dengan nilai koefisien Dice sebesar 0,000 - 0,629 menunjukkan bahwa terdapat jarak yang berbeda pada setiap sampel. Berdasarkan analisis bootstrap, diketahui bahwa hubungan antar semua sampel tarsius (*Cephalopachus bancanus*) memiliki tingkat kepercayaan lebih dari 50%. Polimorfisme yang tinggi menunjukkan variasi genetik yang tinggi antar sampel. Marka RAPD mungkin lebih tepat untuk diaplikasikan dimana hubungan antara populasi yang terkait erat menjadi perhatian.

Keywords: *Cephalopachus bancanus, genetic variation, RAPD, tarsier*

INTRODUCTION

Indonesia ranks among the countries with the greatest primate species richness, hosting 60 of the approximately 250 known species worldwide (Supriatna, 2019; Priatna et al., 2023). Remarkably, at least 60% of these species are endemic to the country (Supriatna & Ramadhan, 2016).

Tarsier (*Cephalopachus bancanus*) is a small primate classified as an arboreal nocturnal carnivorous animals. They consume insects, live in trees, and are active at night. Tarsiers are categorized into three genera, distributed across distinct geographical regions: the genus *Cephalopachus* is found in Kalimantan, southern Sumatra, Bangka Belitung Islands, and the Natuna Islands; the genus *Tarsius* is native to Sulawesi and its surrounding islands; and the genus *Carlito* is located in the southern Philippines and nearby islands (Groves & Shekelle, 2010). Regarding conservation status, *Cephalopachus bancanus* is nationally protected under Government Regulation No. 7 of 1999 in Indonesia. Globally, the International Union for the Conservation of Nature (IUCN) classified its conservation status as "Vulnerable" in 2008 (Shekelle & Yustian et al., 2020).

Molecular genetic analysis enables the identification of genetic variations among individuals within a population. Tarsiers (*Cephalopachus bancanus*) inhabiting the islands of Bangka and South Sumatra are believed to share a common lineage, yet they may exhibit genetic differences driven by adaptations to distinct geographical environments. A key method for assessing such genetic variation involves using genetic or molecular markers (Yuliana & Enung, 2018).

The RAPD technique was selected due to its ability to detect high levels of polymorphism and generate high-quality genetic markers. This method requires only a small quantity of DNA, does not necessitate prior sequence information about the sample, and can reveal specific bands unique to the presence of genetic variation. (Annisa et al., 2021).

The permit for conducting the genetic access study was based on the decree of the Director General of Natural Resources and Ecosystem Conservation (Decree No.SK.83/KSDAE/SET.3/KSA.2/3/2022) concerning permission to access the genetic resources of wild animals. A prior study by Widayanti et al. (2014) investigated genetic variation in tarsiers using the RAPD-PCR method with two samples, *Cephalopachus bancanus bancanus* and *Cephalopachus bancanus borneanus*. However, the sample size in their study was limited, and of the ten RAPD primers tested, only four demonstrated polymorphism.

METHODS

Genetic Materials

This study analyzed genetic variations in Tarsiers (*Cephalopachus bancanus*) using genetic material obtained from eight individuals. Six individuals originated from Petaling and Kemuja villages in Bangka, one from Batu Gane village in South Sumatra, and one preserved specimen from Padang Bindu village in South Sumatra. Samples included non-destructively collected body materials such as blood, hair, tissue, and feces. All samples were stored in a cool box or insulated bag to ensure preservation for subsequent DNA extraction in the laboratory. All samples were put into a cool box or insulated bag for DNA extraction in the laboratory. DNA isolation from blood, hair, and tissue samples was carried out using the QIAmp Fast DNA Stool minikit, while the Zymo Quick DNA miniprep plus fecal/soil kit was used for faecal samples.

PCR amplification

The amplification process was performed using the Random Amplification of Polymorphic DNA (RAPD) method. Prior to amplification, all necessary materials were prepared and combined into a master mix. In this study, DNA amplification was conducted using the T100 Thermal Cycler with a set of 10 RAPD primers.

RAPD data analysis

The DNA bands visualized through PCR-RAPD are converted into binary data, where the presence of a band is assigned a value of 1, and its absence is assigned a value of 0. This binary data is then input into Microsoft Excel for organization. Once structured, the data is transferred to an NTedit table and analyzed using NTSYS software version 2.10. A dendrogram is generated employing the Unweighted Pair Group Method with Arithmetic Mean (UPGMA) and the Jaccard Coefficient of Similarity. The Dice coefficient is utilized to calculate the similarity matrix or index. To assess the confidence level of the UPGMA-based dendrogram, bootstrap analysis is performed using the FreeTree program with 1,000 iterations.

RESULTS AND DISCUSSION

The successful amplification and visualization of DNA samples (Figure 1) indicate that the primers used are complementary to the nucleotide sequences of the Tarsier (*Cephalopachus bancanus*) genome. Conversely, the failure to amplify and visualize certain DNA samples suggests that the primer sequences were not complementary to the nucleotide sequences of the Tarsier genome (Williams et al., 1990). Zein (2013) highlighted that the visualization of monomorphic or polymorphic OPE 19 and OPF 04 bands generated through amplification is not consistently clear. This variability arises based on the abundance of DNA fragment copies. When the number of copies is high, the corresponding bands appear more fluorescent, thicker, and distinctly visible. Conversely, a lower number of DNA fragment copies results in bands that are less fluorescent, thinner, and less distinct.

The genetic variation is indicated by the percentage of polymorphisms presented in Table 1. Despite two primers failing to amplify any Tarsius DNA samples, the overall polymorphism percentage achieved was 80%, reflecting a high degree of polymorphism. This aligns with the criteria established by Fajarudin et al. (2010), who defined a high level of polymorphism as having a percentage exceeding 50%. Furthermore, Welsh et al. (1996) highlighted that genetic variation is represented by the percentage of polymorphic bands or the proportion of polymorphic loci relative to the total loci identified.

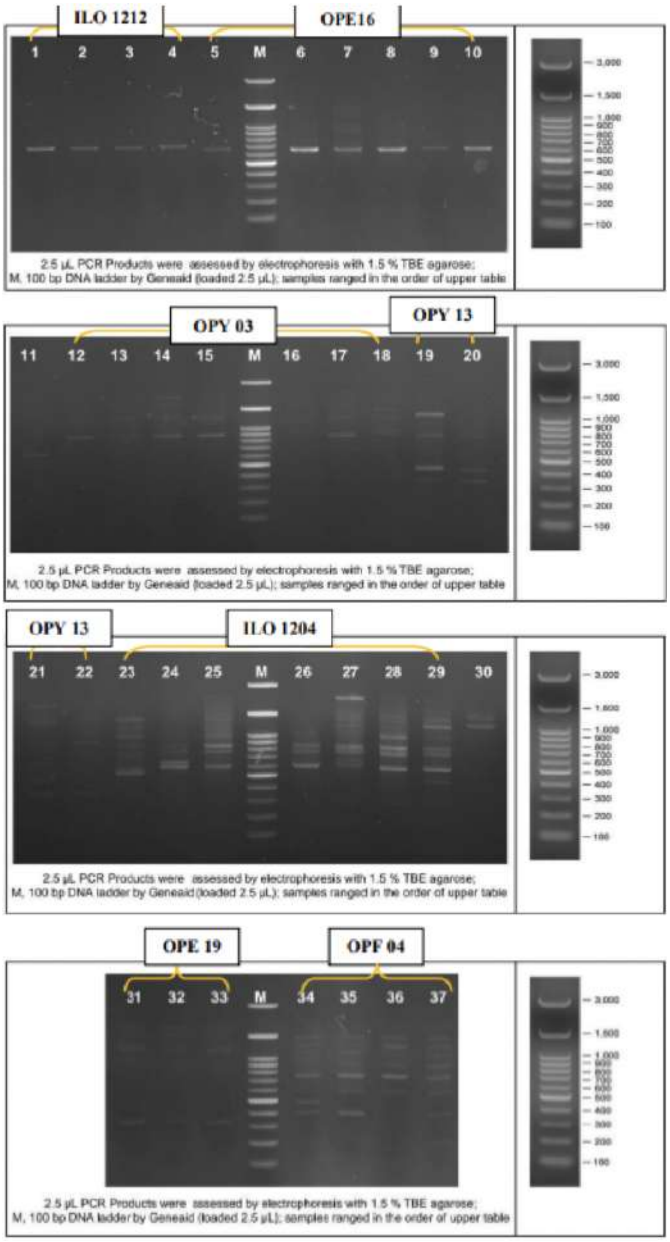

Figure 1. Result of PCR-RAPD.

The samples exhibiting the highest similarity index are Sample #3 and Sample #4, with a similarity index of 0.629 (Table 2). Conversely, the lowest similarity index is observed between Sample #5 and Sample #8, with a value of 0.000. A similarity index score approaching 1 or exceeding 0.5 indicates greater genetic similarity between species. In contrast, a score nearing 0 or below 0.5 reflects increasing genetic divergence among species (Wijayanto et al., 2013).

Table 1. Percentage of polymorphism.

No	Primer	N of Monomorphic Bands	N of Polymorphic Bands	N of Amplified Bands	Percentage
1	ILO 1212	0	2	2	100%
2	OPE 16	0	7	7	100%
3	OPY 03	0	11	11	100%
4	OPY 13	0	8	8	100%
5	ILO 1204	0	17	17	100%
6	OPE 19	0	9	9	100%
7	OPE 17	0	0	0	0%
8	OPF 06	0	0	0	0%
9	OPF 04	0	21	21	100%
10	ILO 525	0	14	14	100%

Table 2. Similarity index.

	Tarsius 1	Tarsius 2	Tarsius 3	Tarsius 4	Tarsius 5	Tarsius 6	Tarsius 7	Tarsius 8
Tarsius 1								
Tarsius 2	0.302							
Tarsius 3	0.245	0.439						
Tarsius 4	0.200	0.486	0.629					
Tarsius 5	0.140	0.196	0.154	0.205				
Tarsius 6	0.295	0.196	0.200	0.205	0.474			
Tarsius 7	0.193	0.138	0.109	0.123	0.314	0.396		
Tarsius 8	0.032	0.034	0.029	0.037	0.000	0.033	0.050	

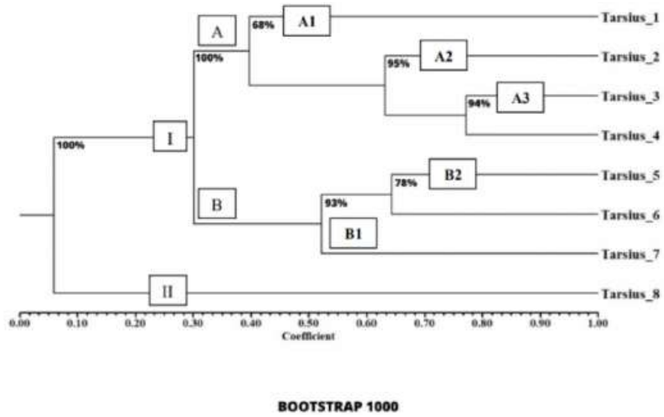

Figure 2. Dendogram relationship of the samples.

The relationship between Tarsiers (*Cephalopachus bancanus*) from South Sumatra and Bangka Island is depicted in Figure 2. The dendrogram indicates that cluster analysis separates the eight samples into two major groups. The first group is further divided into two sub-groups, designated as A and B. Sub-group A comprises Tarsiers #1, #2, #3, and #4, while sub-group B includes Tarsiers #5, #6, and #7. The second group contains only a single sample, identified as Tarsier #8.

The bootstrap analysis revealed a high range of values, spanning from 68% to 100%. The lowest bootstrap value, 68%, was observed at branch/node A1, which links sample #1 with the other samples. Conversely, the highest values, reaching 100%, were recorded at the branches/nodes associated with Group I, Group II, Group A, and Group B. According to Reddy et al. (2009), bootstrap values closer to the maximum of 100% indicate higher statistical confidence in the clustering. A cluster is generally considered statistically robust if its bootstrap value exceeds 50%.

CONCLUSION

The findings of this study reveal that the genetic variation of the tarsier (*Cephalopachus bancanus*) populations from South Sumatra and Bangka Island, analyzed using Random Amplified Polymorphic DNA (RAPD) molecular markers, is characterized by a 100% polymorphic band percentage. Cluster analysis indicates that the tarsiers from these regions form two primary clusters. Within the ingroup, individuals labeled Tarsier #1 through Tarsier #7 occupy distinct branches within the dendrogram, whereas Tarsier #8 is positioned in the outgroup. Among the analyzed samples, the closest genetic relationship is observed between sample #3 and sample #4, while the most genetically distant sample is Tarsier #8.

REFERENCES

Annisa, N., Akyuni, Q., Putri, F.R., Kanaya, O.N., Fauziah, N., Wahyuni, Y., Satria, R., & Achyar, A. (2021). Analisis variasi genetik Semut Ratu Pheidole sp. menggunakan teknik RAPD PCR. *Prosiding SEMNAS BIO 2021, 1(2): 1070-1076*. https://doi.org/10.24036/prosemnasbio/vol1/272

Fajarudin, A., & Poerba, Y.S. (2010). Penampilan random amplified polymorphic DNA pada *Azadirachta indica* A . Juss dari Taman Nasional Baluran. *J. Tek. Ling 11(1): 61–69*.

Fan H., & Gulley M.L. (2000). *Molecular Pathology Protocols: Methods in Molecular Medicine*. Totowa, NJ: Humana Press Inc.

Glasel J.A. (1994). Validity of nucleic acid purities monitored by 260 Nm/280 Nm absorbance ratio. *BioTechniques. 18(1): 62-62*.

Groves, C., & Shekelle, M. (2010). Genera and spesies of Tarsiidae. *International Journal of Primatology, 31(6): 1071- 1082*.

Priatna, D., Hidayat, A., Istiadi, Y., Nurwati, A., Yanuar, A., & Susilo, A. (2023). Daily behaviour and home range of adult rehabilitant Javan slow loris (*Nycticebus javanicus* É. Geoffroy, 1812) in Gunung Sawal Nature Reserve, Ciamis, West Java. *Indonesian Journal of Applied Environmental Studies, 4(1): 46-54*. DOI: 10.33751/injast.v4i1.3107

Reddy, C.S., Babu, A.P., Swamy, B.P.M., Kaladhar, K., & Sarla, N. (2009). ISSR markers based on GA and AG repeats reveal a genetic relationship among rice varieties tolerant to drought, flood, or salinity. *J. Zhejiang Univ. Sci. B., 10(2):133-141*.

Shekelle, M., &Yustian, I. (2020). *Cephalopachus bancanus* The IUCN Red List of Threatened Species 2020: e.T39764A17992286. https://dx.doi.org/10.2305/IUCN.UK.2020-3.RLTS.T39764A17992286.en. Accessed on 21 July 2022.

Supriatna, J. (2019). *Field Guide to the Indonesia Primates*. Jakarta: Yayasan Pustaka Obor Indonesia.

Supriatna, J., & Ramadhan, R. (2016). *Pariwisata Primata Indonesia*. Jakarta: Yayasan Pustaka Obor Indonesia.

Thieman, W.J., and Michael, A.P. (2013). *Introduction to Biotechnology*. New York, USA: Pearson Publisher.

Welsh, J., David, R., & Michael, M. (1996). *DNA and RNA Fingerprinting Using Arbitrarily Primer PCR. In PCR Strategies*. New York: Academic Press: p. 247- 276.

Widayanti, R., Susmiati, T., Pramarta, A., Hardian, A.B., Budiariati, V., Istiqomah., dan Khesara, S.P.N. (2014). Kajian Keragaman Genetik *Tarsius bancanus bancanus* dan *Tarsius bamcanus borneanus* dengan Teknik PCR-RAPD. *Prosiding Seminar Nasional: Peran Rumah Sakit Hewan dalam Penanggulangan Penyakit Zoonosis. 105-117*.

Wijayanto T., Dirvamena., & La, E. (2013). Hubungan Kekerabatan Aksesi Pisang Kepok (*Musa paradisiaca formatypica*) di Kabupaten Muna berdasarkan karakter Morfologi dan Penanda RAPD. *Jurnal Agrotekno, 3(3): 163-170*.

Williams, J. G., Kubelik, A. R., Livak, K. J., Rafalki, J. A., & Tinge, S. V. (1990). DNA Polymorphism Amplified by Arbitrary Primers is Useful as Genetic Markers. *Nucleic Acid Res., 18(22):6531–6535*. doi: 10.1093/nar/18.22.6531 186531-186535.

Yuliana G.D.A., & Eunung, S. M. (2018). Evaluasi keragaman genetik sembilan varietas rambutan (*Nephelium lappaceum*) dengan Marka RAPD. *Biopropal Industri, 9(1): 01-08*.

Zein, M. S. A., & Prawiradilaga, D. M. (2013). *DNA Barcode Fauna Indonesia*. Jakarta: Prenada Media.

GUIDELINES FOR AUTHORS

Submission Preparation Checklist

As part of the submission process, authors are required to check off their submission's compliance with all of the following items, and submissions may be returned to authors that do not adhere to these guidelines.

- The submission has not been previously published, nor is it before another journal for consideration (or an explanation has been provided in Comments to the Editor).
- The submission file is in OpenOffice, Microsoft Word, or RTF document file format.
- Where available, URLs for the references have been provided.
- The text is single-spaced; uses a 12-point font; employs italics, rather than underlining (except with URL addresses); and all illustrations, figures, and tables are placed within the text at the appropriate points, rather than at the end.
- The text adheres to the stylistic and bibliographic requirements outlined in the Author Guidelines.

Author Guidelines

The Indonesian Journal of Applied Environmental Studies will publish original work by:

- Indonesian or foreign scientists on any aspect of Indonesian environmental sciences, including environmental chemistry, environmental biology, ecology geoscience and environmental physics. Appropriate subjects include basic and applied research on atmospheric, terrestrial and aquatic environments pollution control and abatement technology, conservation of natural resources, environmental health study and toxicology, environmental quality assessment, environmental standards and criteria.

The Indonesian Journal of Applied Environmental Studies will publish original work by:

- Enhances understanding of environmental needs in Indonesia
- Improve environmental intervention and management in Indonesia
- Enhances the understanding of Indonesia's environmental management

The Journal language will be in English with abstracts in Bahasa Indonesia as well as English. Authors of full papers are encouraged to provide a Bahasa Indonesia/English translation of their abstract.

Papers and Short Communications

Full Research Papers (2,000-7,000 words) and Short Communications (200-2,000 words) are invited on topics relevant to the Journal's focus, including:

- Environmental chemistry
- Environmental biology
- Ecology geoscience
- Environmental physics
- Basic and applied research on atmospheric
- Terrestrial and aquatic environments pollution control and abatement technology
- Conservation of natural resources
- Environmental health study and toxicology
- Environmental quality assessment
- Environmental standards and criteria

The Journal will not accept descriptions of new species, subspecies or other taxa.

How to Submit a Manuscript

Manuscripts should be submitted through online submission system (OJS) at

https://journal.unpak.ac.id/index.php/InJAST/index

In the cover letter, the Lead Author must confirm that:

- The submitted manuscript has not been published elsewhere
- All of the authors have read the submitted manuscript and agreed to its submission
- All research was conducted with the necessary approval and permits from the appropriate authorities

Review and editing

All contributors in English are strongly advised to ensure that their spelling and grammar is checked by a native English speaker before the manuscript is submitted to the Journal. The Editorial Team reserves the right to reject manuscripts that are poorly written.

Submission is only in English and the Journal secretariat will undertake a preliminary review of all manuscripts for suitability of content and format. Manuscripts that are rejected at this stage will not be sent for peer review and translation.

Manuscripts that pass through the preliminary review will be peer reviewed by a minimum of two reviewers. Authors are welcome to suggest appropriate reviewers.

Proofs will be sent to authors as a portable document format (PDF) file attached to an e-mail note. Corrected proofs should be returned to the Editor within 3 days of receipt. Minor corrections can be communicated by e-mail.

The Editorial Team also welcomes contributions to the other sections of the journal:

News

Concise reports (<300 words) on news of general interest to the study and management of Indonesia's environment. News reports may include,

- Announcements of new initiatives; for example, the launch of new projects, conferences or funding opportunities.
- Announcements of important new reports or other publications related to Indonesian environmental management.
- Summaries of important news from an authoritative published source; for example, new research technique, or a recent development in applied environmental management.
- Summaries and analysis of new policies, decrees and laws relevant to the Indonesian environmental management.

Letters to the Editor

Informative contributions (<650 words) in response to material published in the Journal.

Preparation of manuscripts

Full papers follow the style and format of papers published in the journal Conservation Biology. Authors should consult examples in Conservation Biology for guidance on general style.
Contributions should be in UK English, double-spaced and in 'doc, 'rtf' or 'wpd' format, preferably as one file attached to one covering e-mail.

The cover page should contain; The title and full mailing address, e-mail address and address of the Lead Author and all additional authors.

Contributing Papers should contain the following sections and be arranged in the following order: Abstract, Introduction, Methods, Results, Discussion, Acknowledgments, Literature Cited. Tables, figures and Plates (including legends), if included, should follow the Literature Cited.

All pages should be numbered consecutively. Do not number section headings or subheadings.

Title: This should be a succinct description of the work, in no more than 20 words.

Abstract: Abstracts should only be submitted for Full Papers. This should describe, in 100-300 words, the aims, methods, major findings and conclusions. It should be informative and intelligible without reference to the text, and should not contain any references or undefined abbreviations. Authors are encouraged to submit and English translation of Indonesian text and an Indonesian translation of an English text.

Keywords: From five to eight pertinent words, in alphabetical order.

Literature cited in text: Enclose citations in text in parentheses e.g. "Asian tapirs are no elephants when it comes to seed dispersal (Campos-Arceiz et al., 2011)."

Use an ampersand (&) between author surnames when the citation is parenthetical: (Traeholt & Idris, 2011).

When a citation is not parenthetical, use "and": "Our results agree with the predictions of Wolf and Rhymer (2001)."

For citations with more than two authors, use et al.: (Campos-Arceiz et al., 2011). Do not italicize et al.

List parenthetical citations in alphabetical order and chronologically from oldest to most recent and separate entries with a semicolon: (Campos-Arceiz et al., 2011; Geissman, 2009, 2010).

Separate the years with commas when citing multiple papers by the same author: (Corlett, 2007, 2010; Geissman, 1984, 1995, 1999, 2000).

"In press" means the cited paper has been accepted unconditionally for publication. Provide the year of publication in the text (Bird, 2010) and in Literature Cited section provide the volume number, and substitute "in press" for page numbers (Bird, I.M. 2010. Nesting success in arid lands. Conservation Biology 24: in press.).

Papers in review must be cited as unpublished and should not appear in the Literature Cited section.

Use an initial for the first (given) name and spell out the last name (surname) for other sources of unpublished data or information: (R. Fowler, unpublished data; M.E. Soulé, personal communication).

Software: capitalize the first letter only if the name of the program is a word (e.g., Vortex, ArcGIS). If the name of the program is not a word, use all capital letters (e.g., SAS).

The following are examples of Literature Cited house style:

Campos-Arceiz, A. and R.T. Corlett (2011). Big animals in a shrinking world—studying the ecological role of Asian megafauna as agents of seed dispersal. *Innovation* 10: 50–53.

Campos-Arciez, A., Larringa, A.R., Weerasinghe, U.R., Takatsuki, S., Pastorini, J., Leimgruber, P., Fernando, P. and L. Santamaria (2008). Behavior rather than diet mediates seasonal differences in seed dispersal by Asian elephants. *Ecology* 89: 2684–2691.

MacArthur, R.H. & Wilson, E.O. (1967). The Theory of Island Biogeography. Princeton University Press, Princeton, USA.

Sutherland, W.J. (ed.) (1998). Conservation Science and Action. Blackwell Science, Oxford, UK.

Beck, B.B., Rapaport, L.G. & Stanley Price, M.R. (1994). Reintroduction of captive-born animals. In Creative Conservation: Interactive Management of Wild and Captive Animals (eds P.J.S. Olney, G.M. Mace & A.T.C. Feistner), pp. 265-286. Chapman & Hall, London, UK.

Traeholt, C., Bonthoeun, R., Rawson, B., Samuth, M., Virak, C. and Sok Vuthin (2005). Status review of pileated gibbon, Hylobates pileatus and yellow-cheeked crested gibbon, Nomascus gabriellae, in Cambodia. Fauna & Flora International, Phnom Penh, Cambodia.

Sun H. (2000). Status of the tiger and its conservation in Cambodia. MSc thesis, University of Minnesota, Minneapolis, USA.

IUCN (2010). 2010 IUCN Red List of Threatened Species. http://www.redlist.org [accessed 1 February 2011].

Biography: This should describe the main research interests of all authors (<150 words total), apart from what is obvious from the subject of the manuscript and the authors' affiliations.

Tables, figures and plates: These should be self-explanatory, each on a separate page and with an appropriate caption. Figures can be submitted in colour as well as in black and white. The Editorial Team may decide to convert coloured figures into black and white should it be necessary due to printing cost and without diluting the message. Plates (black and white only) will only be included in an article if they form part of evidence that is integral to the subject studied (e.g., a photograph of a rare species), if they are of good quality, and if they do not need to be printed in colour.

Appendices: Lengthy tables, and questionnaires are discouraged. In special circumstances these may be made available for viewing online.

Species names: The first time a species is mentioned, its scientific name should follow in parenthesis and in italics: e.g., Asian elephant (*Elephas maximus*). English names should be in lower case throughout except where they incorporate a proper name (e.g., Asian elephant, Cookson's wildebeest, long-billed vulture).

Abbreviations: Full expansion should be given at first mention in the text.

Units of measurement: Use metric units only for measurements of area, mass, height, etc.

The Indonesian Journal of Applied Environmental Studies (InJAST) is co-published biannually by the Graduate School of Environmental Management at the Pakuan University, Bogor, Indonesia, and Perhimpunan Cendikiawan Pemerhati Lingkungan Indonesia, the Indonesian Association of Environmentalist Scholars (PERWAKU), in collaboration with Belantara Foundation. The Graduate School of Pakuan University, through its Study Programme of Environmental Management, is having a vision as a center for developing a qualified, tough and dignified human resources. PERWAKU is having a vision of towards environmentally friendly Indonesia.

Indonesian Journal of Applied Environmental Studies

journal.unpak.ac.id
Volume 5 • Number 2 • October 2024
P - ISSN : 2722 - 0133
E - ISSN : 2722 - 0141

P-ISSN: 2722 - 0133 E-ISSN: 2722 - 0141

9 772722 013002 9 772722 014009

Pakuan University

PERWAKU

Supported by Belantara FOUNDATION