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Global Journal of Environmental Science and Management (GJESM) is an international scholarly refereed research journal which aims to promote the theory and practice of environmental science and management. A broad outline of the journal's scope includes; peer reviewed original research articles, case and technical reports, reviews and analyses papers, short communications and notes to the editor, in interdisciplinary information on the practice and status of research in environmental science and management, both natural and man-made. The main aspects of research areas include, but are not exclusive to; environmental chemistry and biology, environments pollution control and monitoring, transport and fate of pollutants in the environment, concentrations and dispersion and trace of wastes in air, water, and soil, point and non-point sources pollution, heavy metals and organic compounds in the environment, atmospheric pollutants and trace gases, solid and hazardous waste management; soil biodegradation and bioremediation of contaminated sites; environmental impact assessment, industrial ecology, ecological and human risk assessment; improved energy management and auditing efficiency and environmental standards and criteria.

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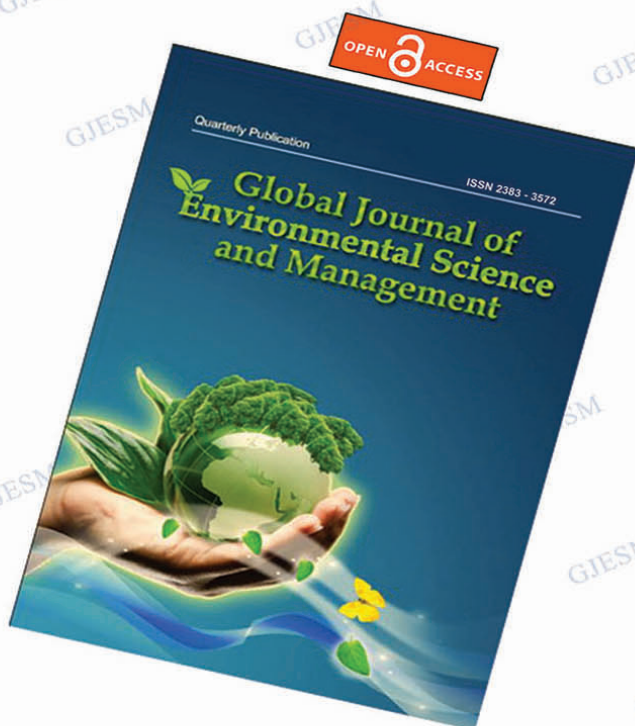
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## ORIGINAL RESEARCH ARTICLE

# Acute effects on hepatic biomarkers in the freshwater native fish *Aequidens metae* exposed to polycyclic aromatic hydrocarbons

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## ABSTRACT

**BACKGROUND AND OBJECTIVES:** Polycyclic aromatic hydrocarbons are present in all environmental matrices. Polycyclic aromatic hydrocarbons-rich wastewater from the oil industry is discharged into natural water bodies. Detritivorous fish shown the effects of pollutants in water. Biomarkers of effect make it possible to demonstrate exposure to xenobiotics such as polycyclic aromatic hydrocarbons. The aim of the present study was to evaluate the hepatic and erythrocyte response in *Aequidens metae*, a detritivorous fish, exposed to polycyclic aromatic hydrocarbons in terms of morphological, biochemical, and genotoxic changes.

**METHODS:** Juveniles of *Aequidens metae* were exposed to 50 microgram per gram body weight of beta-naphthoflavone, 100 microgram per gram of naphthalene, 50 microgram per gram of phenanthrene and 10 microgram per gram of benzo[a]pyrene, for 72 hours. Water quality variables, total protein content, 7-ethoxyresorufin-O-deethylase activity, liver histopathological changes and genotoxic alterations in peripheral blood were measured during the assay.

**FINDINGS:** In polycyclic aromatic hydrocarbons-exposed fish, analysis of liver tissue revealed parenchymal lesions and changes in the number and shape of hepatocyte nuclei. On the other hand, only fish exposed to benzo[a]pyrene shown significant increase in the 7-ethoxyresorufin-O-deethylase activity compared to solvent control. In peripheral blood erythrocytes, increased presence of nuclear abnormalities was higher in fish exposed to phenanthrene, followed by benzo[a]pyrene, beta-naphthoflavone, and naphthalene.

**CONCLUSION:** It is concluded that *Aequidens metae* is a suitable bioindicator for polycyclic aromatic hydrocarbons monitoring in aquatic ecosystems. Phenanthrene reveals for the first time a greater genotoxic effect than benzo[a]pyrene at sublethal concentrations. Juveniles of *Aequidens metae* exposed to concentrations of polycyclic aromatic hydrocarbons close to those found in the environment showed health-compromising damage.

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## INTRODUCTION

Oil activity in Colombia plays a decisive role in the country's economic balance and development (Beltrán and Vargas, 2014). In turn, hydrocarbon extraction generates environmental impacts that include contamination of soil, surface water and groundwater, which involves health risks (Ossai et al., 2020). Among the compounds associated with oil are polycyclic aromatic hydrocarbons (PAH), which stand out for their recalcitrance and high toxicity; PAH are among the most harmful pollutants (Tariq et al., 2015). As a result, they are the subject of intense research because they are considered priority pollutants by regulatory agencies such as the U.S. Environmental Protection Agency (McGrath et al., 2019). They possess two or more benzene rings, with widely varying molecular characteristics that establish their toxicological properties. PAH are recalcitrant organic compounds derived from fossil fuels and coal and from incomplete combustion, among others (Cousin and Cachot, 2014). Despite this scenario, in Colombia, there are scarce studies on the effects of exposure to PAH on biota. This knowledge gap makes it difficult for regulatory agencies to make environmental decisions to identify the impacts generated by anthropogenic activities. Environmental stressors can trigger biochemical and morphological alterations in aquatic organisms, including fish; these tissue modifications may indicate exposure to contaminants such as PAH available in water bodies (Honda and Suzuki, 2020). Histological analysis provides evidence of possible immediate mechanisms of BaP co-exposure and effects on the architecture of organs such as the liver in species exposed to PAH (Briaudeau et al., 2021). Histological analysis can detect the effects of sublethal stressors in tissues such as the liver, which is crucial for the detoxification of xenobiotics. (Wolf, 2013). Given the location of fish in food chains, the consequences of exposure to PAH motivate research (Wang et al., 2021). Since fish are used as a food source, the bioaccumulative effect can impact the health of consumers (Javed and Usmani, 2019; Noman et al., 2022). Given the varied results of field studies that have the inability to measure all pollutants present in water bodies, studies that individually identify the effects of exposure to each compound are required (Gan et al., 2021; Olayinka et al., 2019; Yu et al., 2019). In this regard, exposure studies to individual PAH such as phenanthrene

(PHE) have been performed in cachama blanca (*Piaractus brachipomus*) for 11 days, which showed an increase in hepatic lipid peroxidation in fish exposed to 10 microgram per gram ( $\mu\text{g/g}$ ) of body weight (BW) (Mora-Solarte et al., 2020), in toadfish (*Opsanus beta*) exposed intraperitoneally to 5  $\mu\text{g/g}$  doses of naphthalene (NAP) and PHE for 72 hours (h), increased glucocorticoid to stress response was evidenced (Reddam et al. 2017) and, in orange-spotted grouper (*Epinephelus coioides*) exposed intraperitoneally to doses of 2, 20 and 35 milligram per kilogram (mg/kg) of benzo[a]pyrene (BaP) after 4 days showed a decrease in total leukocyte erythrocytes, lysozyme activity and immunoglobulin M (IgM) level (Khaniyan et al., 2016). In the Orinoquia region, due to abundant crude oil extraction, PAH including NAP, PHE, and BaP, among others, are deposited on the beds of water bodies, making them accessible to benthic fish (Velasco-Santamaría et al., 2019). In this region, *Aequidens metae* is one of the most abundant and easily detected benthic and detritivorous not restricted fish. Furthermore, this fish occupies an intermediate place in the food chain and is a potential vector of biomagnification due to its detritivores feeding habits and it is also adapted to laboratory conditions. In this context, *A. metae* has been proposed as a potential bioindicator of exposure to environmental contaminants (Corredor-Santamaría et al., 2016; Corredor-Santamaría et al., 2019). In juvenile cichlid *Aequidens metae* native to the Colombian Orinoquia, biomarkers of exposure were used to analyze the effect of three PAH widely distributed in water bodies. The aims of the present study were to determine the suitability of the intraperitoneal route of administration at sublethal concentrations in acute assay to 3 PAH commonly found in the environment and one PAH as a model of induction of 7-ethoxyresorufin-O-deethylase (EROD) activity, histopathological alterations in liver and genotoxic alterations in peripheral blood in the neotropical cichlid *Aequidens metae*. This study was conducted at the Laboratory of Toxicology and Biotechnology of the Universidad de los Llanos in Colombia, between the years 2019 and 2020.

## MATERIALS AND METHODS

### Biological material and exposure experiments

Thirty *Aequidens metae* juveniles with BW of  $8.24 \pm 0.40$  gram (g) and body length of  $6.86 \pm 0.25$

centimeter (cm) was acquired from the Laboratory of Toxicology and Biotechnology of the Universidad de los Llanos. The fish were randomly housed in 20 liter (L) capacity glass aquaria with constant aeration. Prior to the exposure period, to evaluate the behavior of the fish, they were monitored for 15 days, fed every 24 h with commercial feed at 3 percent (%) of the biomass. A semi-static system was applied, 30 % of the water volume was restored, and a temperature of 25 Celsius degree (°C) was maintained with a photoperiod of 12 h of light and 12 h of darkness. Physicochemical water quality parameters, including pH, with pH meter (Hanna Waterproof, Mauritius), temperature and dissolved oxygen were measured and a multiparameter equipment (YSI professional plus, Ohio USA), nitrite and ammonium were recorded with a HACH kit, were monitored daily. Fish were injected intraperitoneally with NAP (CAS no. 91-20-3, Sigma-Aldrich) at doses of 100 µg/g BW, PHE (CAS no. 85-01-8, Sigma-Aldrich) at doses of 50 µg/g, BaP (CAS no. 50-32-8, Sigma-Aldrich), at doses of 10 µg/g, and β-Naphthoflavone (BNF) (CAS no. 6051-87-2, Sigma-Aldrich) at doses of 50 µg/g, diluted in canola oil as PAH solvent (Oliveira et al., 2013; Santos et al., 2018), another group was injected with PAH solvent and another group without injection, each group with five replicates, for 72 h. All fish were injected at a final volume of 5 microliters per gram (µL/g) BW. After the exposure period was completed, the fish were immersed in an anesthetic solution containing 300 milligrams per liter (mg/L) of 2-phenoxyethanol, J. T. Baker, Phillisburg, USA), after losing the swimming

axis they were desensitized by cervical dislocation. Fish fork length (ichthyometer) and weight (Ohaus Scout Pro® digital) were recorded. The liver was removed and divided for biochemical and histological procedures, and immediately collected tissues were preserved in vials under freezing at -70°C and in vials containing buffered formaldehyde at room temperature, respectively (Fig. 1). Doses and exposure times were selected according to previous studies of induction of enzymes of intermediary metabolism in the hepatic tissue with NAP, PHE, and BaP in golden tilefish (*Lopholatilus chamaeleonticeps*), yellowfin seabream (*Acanthopagrus latus*), and zebrafish (*Danio rerio*), respectively (Gerger and Weber, 2015; Shirmohammadi et al., 2017; Snyder et al., 2015). The usefulness of intraperitoneal injection has been proven in various studies of exposure to toxic xenobiotics including PAH since facilitates the direct entry of the compounds into the organism, attenuating losses during administration and the release of residues into the environment (Karami et al., 2011). This research project was carried out based in accordance with the norms established in Resolution No. 8430 of 1993 of the Ministerio de Salud, Colombia and those established by the Bioethics Committee of the Universidad de los Llanos.

#### Hepatosomatic index (HSI)

HSI was calculated based on the ratio of liver weight to the weight of each fish using Eq. 1 (Araújo et al., 2017).

$$\text{HSI} = \text{Liver weight (g)} / \text{Fish weight (g)} \times 100 \quad (1)$$

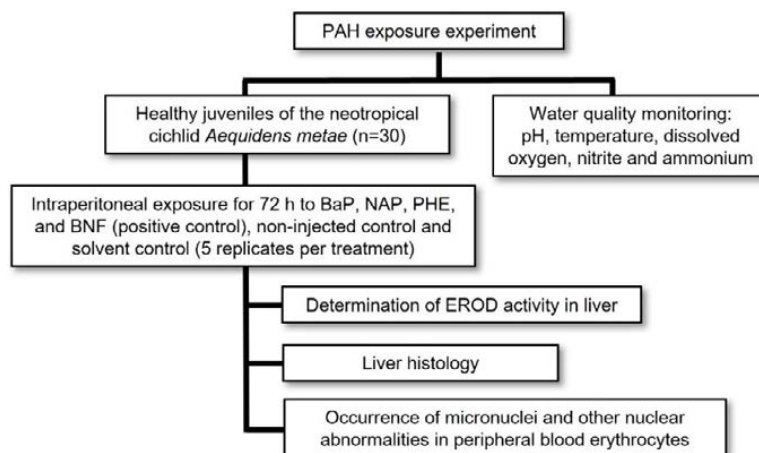


Fig. 1: Summary of the methodology used at the experiment with *Aequidens metae* exposed to PAH during 72 h

#### *EROD assay and protein quantification*

In *A. metae*, hepatic EROD activity was determined based on the protocol proposed by Valdehita *et al.* (2012) after subsequent standardization. During standardization of the determination of EROD activity in liver of *A. metae* after intraperitoneal injection of BaP, the highest level of this biomarker was found at 72 h. Around 30 mg of liver kept at 4°C was homogenized in 1 ml of buffer containing 0 - 1 M tris (hydroxymethyl) aminomethane hydrochloride (Tris-HCl) pH 7.0 - 25 millimolar (mM) sucrose, 150 mM potassium chloride (KCl), 1 mM ethylenediaminetetraacetic acid (EDTA), 1 mM dithiothreitol (DTT), 0 - 25 mM phenylmethylsulfonyl fluoride (PMSF) and 20 % glycerol). The tissue homogenate was centrifuged for 10 min at 6000 gravities (*g*). The supernatant was centrifuged for 60 min at 16,000 *g*. The sediment was diluted in 100 microliters (μL) of buffer. EROD activity was measured from total protein concentration (Burke and Mayer, 1974). Fluorescence was recorded on a Cytation 3 spectrophotometer (BioTek®, USA), after the reaction of proteins with Coomassie Brilliant Blue G-250 dye. Finally, a standard curve with bovine serum albumin (BSA) was performed and the absorbance was determined at a length of 595 nanometer (nm).

#### *Histological evaluation*

Tissues were fixed in buffered formalin (pH 7.2) at 4 °C for 5 days with increasing concentrations of ethanol between 70 and 100 % the tissues were dehydrated. Then the tissues were embedded in paraffin (MERCK) and sectioned at 3 micrometers (μm) with a CUT 5062 (SLEE Medical GmbH, Germany). Hematoxylin and eosin (H and E) staining was applied. Five sections were examined from each fish under an Eclipse-E100 light microscope (Nikon, Japan) with a Nikon camera connected. The appearance of morphological alterations in each tissue was evaluated following the methodology modified by Abalaka *et al.* (2015) based on the degree of tissue change (DTC), which considers the severity of the alterations. Organ function is not compromised at stage I, at stage II function is altered, and at stage III damage is irreversible. For each fish,  $DTC = 10^0 \sum I + 10^1 \sum II + 10^2 \sum III$ , in equation I, II, and III represent the total disruptions observed at stages (*n* = 5), in 30 fields photographed for each fish. Mean DTC was

ranked from 0 to 10 (normal tissue); 11 to 20 (mild to moderate disruption); 21 and 50 (from moderate to severe disruption); 51 and 100 (severe disruption); and higher than 100 (irreparable disruption).

#### *Histometric evaluation*

Hepatocyte nuclei were measured in terms of their diameters (μm) and area (μm<sup>2</sup>) for each fish using ImageJ. Tissue cell proliferation was determined by counting nuclei in 30 visual fields for each fish in a fixed area of 10,000 μm<sup>2</sup>. Values were shown as the mean and standard error of measurements of hepatocyte diameters, area, and nuclei counts for all treatments.

#### *Genotoxicity responses*

From the caudal vessels of each fish, 5 μL of peripheral blood were extracted and stained for 10 min with Wright-methanol (Merck®). Micronucleus (MN) frequency was calculated in 2,000 mature erythrocytes from each fish (Al-Sabti and Metcalfe, 1995) and expressed as the total number of MN per 1,000 cells. Following the criteria of Grisolia *et al.* (2002); Carrasco *et al.* (1990), the frequency of MN and other nuclei anomalies were counted, respectively.

#### *Statistical Analysis*

All results were recorded as mean ± SE. PAH-exposed groups were compared with control groups by one-way analysis of variance (ANOVA) with subsequent Tukey's post hoc test. P value < 0.05 was the threshold value for recognizing significant statistical differences. Programs such as IBM Statistical Package for the Social Sciences (SPSS) statistic 19, GraphPad v 5.0 and SAS Institute Inc. (Cary, NC, USA).

## RESULTS AND DISCUSSION

#### *Physicochemical parameters*

During the experiment, no statistical differences were found in the water quality parameters among treatments (Table 1). Water quality parameters were in accordance with the conditions present in the non-polluted natural environment (Corredor-Santamaría *et al.*, 2021).

#### *Hepatosomatic index*

HSI under stress conditions can increase and is one of the rates most often associated with exposure

Table 1: Monitoring of physical-chemical water parameters during exposure to PAH in *Aequidens metae*

Treatment	Water quality parameters				
	NH <sub>3</sub> (mg/L)	NO <sub>2</sub> (mg/L)	TEMP (°C)	pH	DO (mg/L)
Control not injected	0,057±0,02 <sup>a</sup>	0,01±0,003 <sup>a</sup>	25,71±0,10 <sup>a</sup>	6,41±0,09 <sup>a</sup>	7,5±0,1 <sup>a</sup>
Solvent Control	0,048±0,02 <sup>a</sup>	0,02±0,001 <sup>a</sup>	25,60±0,12 <sup>a</sup>	6,21±0,06 <sup>a</sup>	7,6±0,0 <sup>a</sup>
β-Naphthoflavone	0,051±0,02 <sup>a</sup>	0,02±0,001 <sup>a</sup>	25,36±0,07 <sup>a</sup>	6,23±0,06 <sup>a</sup>	7,8±0,1 <sup>a</sup>
Naphthalene	0,043±0,04 <sup>a</sup>	0,01±0,002 <sup>a</sup>	25,42±0,13 <sup>a</sup>	6,28±0,11 <sup>a</sup>	7,6±0,2 <sup>a</sup>
Phenanthrene	0,036±0,03 <sup>a</sup>	0,02±0,003 <sup>a</sup>	25,31±0,12 <sup>a</sup>	6,36±0,10 <sup>a</sup>	7,9±0,1 <sup>a</sup>
BaP	0,056±0,02 <sup>a</sup>	0,03±0,002 <sup>a</sup>	25,21±0,11 <sup>a</sup>	6,15±0,09 <sup>a</sup>	7,5±0,0 <sup>a</sup>

<sup>a</sup> Shows no significant differences (Tukey test,  $p > 0.05$ ). Temperature (TEMP), Dissolved oxygen (DO).

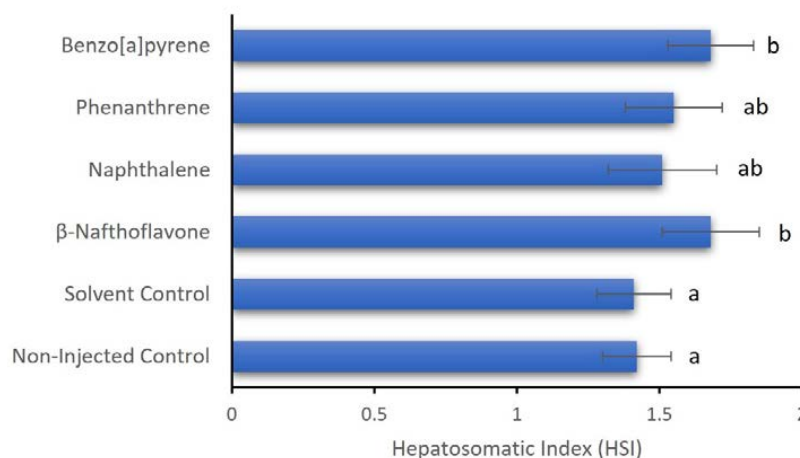


Fig. 2: Hepatosomatic index in *Aequidens metae* exposed to PAH during 72 h. Bars shown the mean  $\pm$  SE ( $n = 5$ ). <sup>ab</sup> Bars with different letters shown statistically significant differences (Tukey-Test,  $p < 0.05$ ) between treatments.

to contaminants (Al-Ghais, 2013; De *et al.*, 2016; Aly and Abouelfadl, 2020).

Increased hepatosomatic index in *A. metae* exposed to BNF and BaP (Fig. 2), compared to non-exposed groups, is possibly due to a significant increase in detoxification processes, which was observed in the evaluation of liver tissue, such as vacuolization, hypertrophy, and hyperplasia of hepatocytes, and increased sinusoidal space. In zebrafish (*Danio rerio*) exposed to 6  $\mu\text{g/L}$  BaP for 15 days, Mai *et al.* (2021) reported similar findings along with increased induction of oxidative stress. Also, in fish exposed to produce waters by oil extraction, which are dominated by two-ring PAH, such as naphthalene an increase in the HIS was observed (Meier *et al.*, 2020).

#### EROD assay and protein quantification

The determination of EROD activity has been routinely employed as an indirect measurement of

the induction of cytochrome P450, family 1 (*CYP1*) expression as a biomarker of exposure to different PAH such as BaP (Jönsson *et al.*, 2010). PAH have been shown to induce CYP-related mixed-function oxidases, and that CYP, family 1, subfamily A (*CYP1A*) activity can be measured in terms of EROD activity, based on the principle that it can catalyze etoxyresorufin into resorufin, whereby the greater the presence of *CYP1A* the greater the EROD activity (Wincent *et al.*, 2016). In this regard, induction of *CYP1* in rainbow trout by BaP after exposure for 12 h has been reported, EROD activity in gills was correlated with the expression level of CYP, family 1, subfamily A, polypeptide 1 (*CYP1A1*) and CYP, family 1, subfamily A, polypeptide 3 (*CYP1A3*), they found that it was higher compared to CYP, family 1, subfamily B, polypeptide 1 (*CYP1B1*) and *CYP1*. *CYP1* mRNA expression levels were induced at a concentration of 1 nM. Whereby, *CYP1A* was more sensitive than *CYP1B* and CYP, family 1, subfamily C (*CYP1C*) to BaP (Gao *et al.*, 2021). It

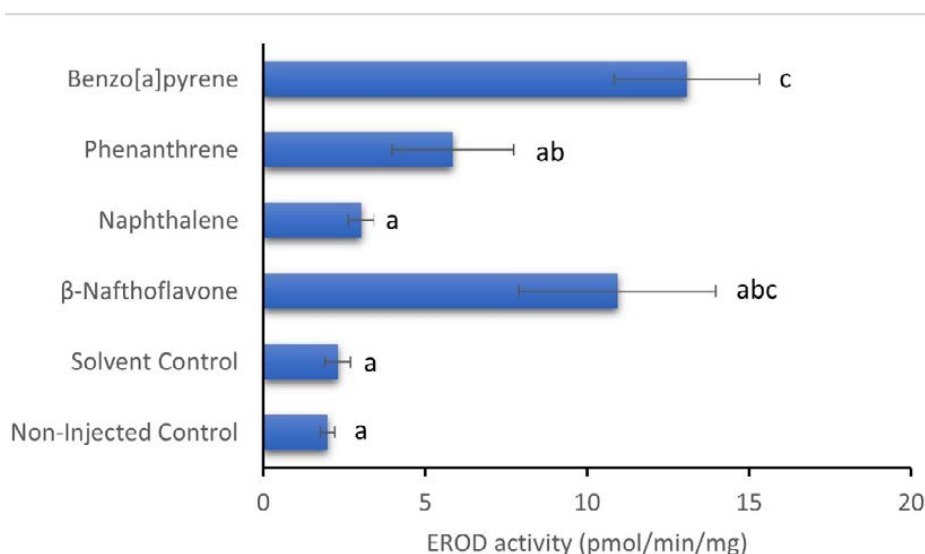


Fig. 3: Hepatic EROD activity in livers of *Aequidens metae* exposed to PAH during 72 h. Bars shown the mean  $\pm$  SE (n = 5). <sup>abc</sup> Bars with different letters shown statistically significant differences (Tukey-Test,  $p < 0.05$ )

has been reported that in Nile tilapia (*Oreochromis niloticus*) EROD activity was induced following 3 and 5 days of exposure to 300  $\mu\text{g/L}$  of BaP, after which, levels returned to their basal state (Rodrigues et al., 2014). It is also reported in rainbow trout (*Oncorhynchus mykiss*) the intraperitoneal administration of BaP at a dose of 2 mg/kg, which induced an increase in EROD activity and micronucleus frequency after 48 h of administration and a recovery after 7 days of EROD activity levels while MN frequency remained higher than in the control group (Fanali et al., 2021). In the current study, an induction of EROD activity after exposure via intraperitoneal route for 72 h was reported (Fig. 3), with return to basal levels after 10 days of injection. Increased EROD activity has been reported in *O. niloticus* exposed to PHE at doses of 50, 100 and 400  $\mu\text{g/L}$  for 4, 8 and 14 days, with higher increases on the fourth day of exposure with 50  $\mu\text{g/L}$  (Xu et al., 2009), in the present study a non-significant increase was observed in those exposed to PHE compared to the non-injected and solvent control groups (Fig. 3).

In the case of the exposure of *A. metae* to naphthalene, the fish showed a slight increase in EROD activity (Fig. 3), with no statistical difference ( $p > 0.05$ ). Cichlids such as *O. niloticus* are sensitive

to low concentrations of naphthalene, Amutha and Subramanian (2010), reported that fish exposed to concentrations from 6 to 14 mg/L showed a gradual increase in EROD activity after 12 h, but after 24 h of exposure, the activity decline at 14 mg/L and fish die. This was not the case in *A. metae* exposed to NAP, probably due to the function of another organ no identified in this study which can exerted the biotransformation of this PAH.

#### Histological evaluation

The liver parenchyma of *A. metae* is formed by hepatocytes with granular cytoplasm surrounded by sinusoids, with spherical nuclei and dark and prominent non-concentric nucleoli. The formation of portal triads was not evidenced (Fig. 4).

Displaced nuclei and vacuolization were evident in the perimeter of hepatocytes (Fig. 4D, E and F) from this organ of PAH-exposed fish (Fig. 4D, E, and F). The control group and the exposed treatments presented alterations corresponding to stage I DTC, including nuclear atrophy, mild nuclear and cytoplasmic hypertrophy, and deformation of the nuclear contour. On the other hand, stage II included hyperemia (Fig. 4C-D) and nuclear degeneration (Fig. 4D), which were higher in *A. metae* exposed to  $\beta$ -naphthoflavone,

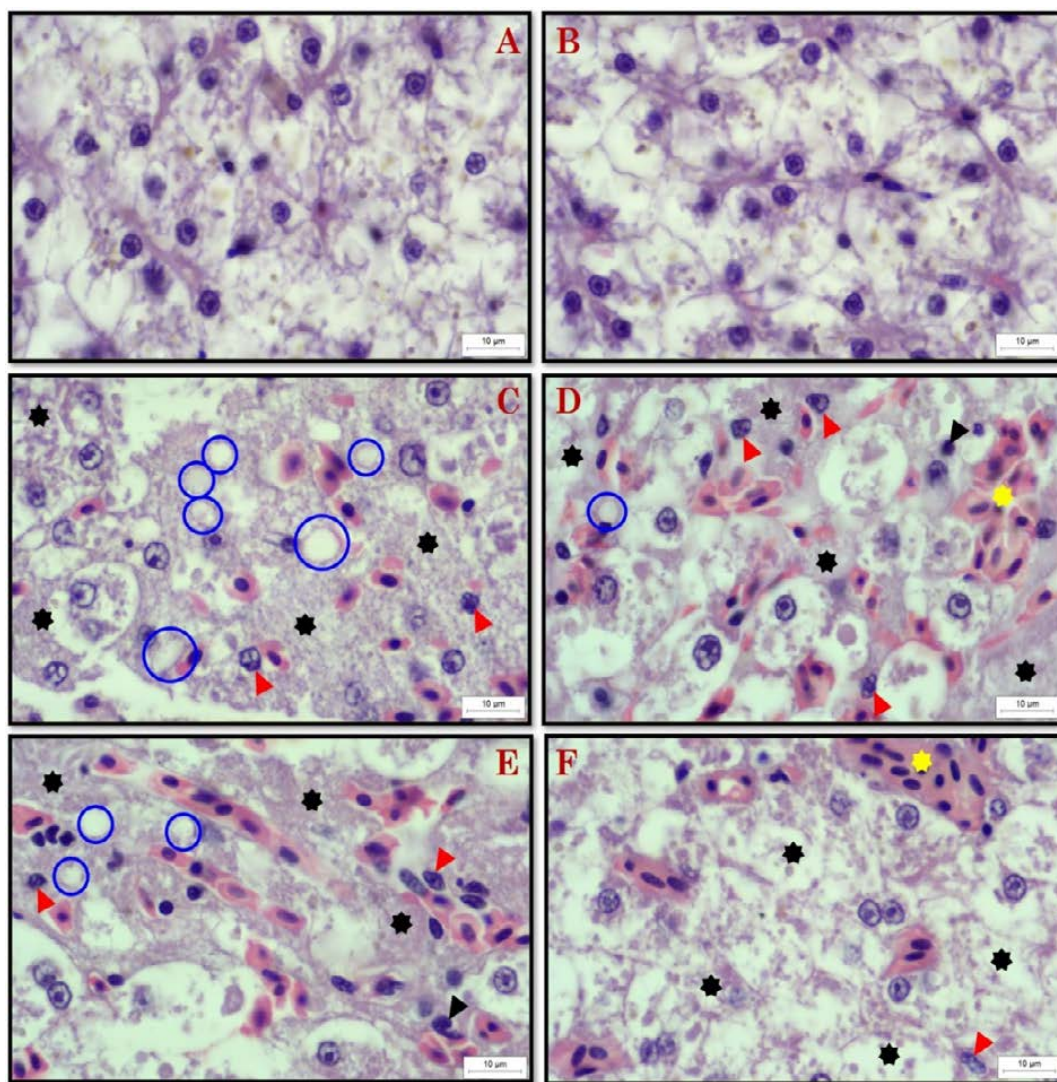


Fig. 4: Disturbances in the liver parenchyma of *Aequidens metae* exposed to PAH during 72 h. A) Non-injected control and B) solvent control show normal tissue with non-concentric nuclei and nucleoli and granular cytoplasm, C) exposed to  $\beta$ -naphthoflavone, D) exposed to naphthalene, E) exposed to phenanthrene and F) exposed to benzo[a]pyrene. Note in the different microphotographs the hyperemia (yellow star), degeneration of the nuclei (red triangle), pyknotic nuclei (black triangle), degeneration of the cytoplasm (black star), vacuolization (blue circle). H and E staining, magnification x 400.

phenanthrene and BaP; in the latter, pyknotic nuclei were more noticeable, together with cytoplasmic degeneration (Fig. 4E-F). It should be noted that the presence of necrosis indicative of stage III was not identified. The increased occurrence of histopathological changes may indicate dysfunctions induced by potentially toxic agents, considering that the liver biotransformation sites are reduced, which may alter the metabolizing functions of xenobiotics

and endogenous substances (Gu and Manautou, 2012; Kostić et al., 2017). Liver DTC in *A. metae* were not considered severe, as no necrotic tissue was observed, and the lesions evidenced corresponded to stages I and II, as reported in the carp (*Capoeta capoeta*) from the Karasu River, Turkey and in crucian carp (*Carassius auratus*), pale chub (*Zacco platypus*), and Korean chub (*Zacco koreanus*) caught in streams contaminated with wastewater from

treatment plants (Dane and Şişman, 2014; Samanta *et al.*, 2018). In *A. metae* exposed to  $\beta$ NF and BaP, the diameter of nuclei and the area of hepatocytes exceeded ( $p<0.05$ ) the values of the control group fish (Table 2). In response to stressors such as toxic metals, an increase in the diameter of hepatocyte nuclei (karyomegaly) has been reported, which may indicate increased biotransformation reactions (Velma and Tchounwou, 2010; Wolf and Wheeler, 2018;). In *A. metae*, exposure to  $\beta$ NF and BaP induced hepatocyte hypertrophy, which could be related to alterations in structure associated with an increase in cellular metabolic rate. More hepatocyte nuclei were counted in *A. metae* exposed to  $\beta$ NF, PHE and BaP than fish in the control groups ( $p<0.001$ ) (Table 2).

In the present study, quantification of the nuclei of hepatocytes made it possible to establish a link with of hepatocyte proliferation which signal possibly the induction of the cell cycle by alterations in liver function produced from PAH such as BaP on the hepatocytes during detoxification of this types of compounds (Regnault *et al.*, 2014). After an acute exposure period of 72 h, and at the concentrations of PAH used, it can be concluded that juvenile *A. metae* develop an early intoxication process, with reversible injuries. The usefulness of histological biomarkers as a tool for assess the sublethal effects of environmental contaminants on a native fish *A. metae* was validated.

### Genotoxicity analysis

Regarding the frequency of micronuclei, an increase of 6.7; 4.9; 4.7 and 4.4 times was observed in erythrocytes from fish exposed to PHE, BNF and BaP, all with  $p<0.0001$  and NAP (0,042), respectively, compared to the solvent control group. Also, notched abnormalities were more frequent in those exposed to PHE 5.5-fold ( $p<0.0001$ ), NAP 5.1-fold ( $p<0.0024$ ) and BaP 4.1-fold ( $p<0.006$ ) compared to the solvent control group. In turn, fish exposed to PHE ( $p<0.0001$ ) and BaP ( $p<0.0019$ ) exhibited a 6.78- and 5.78-fold increase, respectively, in lobed abnormalities compared to the solvent control group. Blebbed nuclear abnormalities occurred more frequently in the PHE ( $p<0.0001$ ), BaP ( $p<0.015$ ), and NAP ( $p<0.0016$ ) exposed groups, 6; 3.9 and 3.9 times compared to the solvent control group. Likewise, binucleated erythrocytes presented higher occurrence in fish exposed to PHE ( $p<0.0001$ ), BaP ( $p<0.013$ ), and NAP ( $p<0.022$ ), 4.3; 3.3 and 2.6 times compared to the solvent control group (Table 3).

The genotoxic alterations found in fish exposed to PAH have been shown in other studies where the DNA damage induced in the liver of Caspian Kutum (*Rutilus frissi kutum*) has been associated with reactive oxygen species induced by BaP, together with the production of secondary metabolites during the biotransformation

Table 2: Degree of tissue change (DTC), average diameter, area and number of the hepatocytes nuclei in the liver tissue of juvenile *A. metae* exposed to different concentrations of PAH after 72 hours

Treatment	Micronuclei	Notched	Lobed	Blebbed	Binucleated
Control not injected	1,11 $\pm$ 0,48 <sup>a</sup>	2,33 $\pm$ 0,17 <sup>b</sup>	0,33 $\pm$ 0,17 <sup>cd</sup>	1,00 $\pm$ 0,33 <sup>c</sup>	0,27 $\pm$ 0,02 <sup>c</sup>
Solvent Control	1,89 $\pm$ 0,26 <sup>a</sup>	2,00 $\pm$ 0,37 <sup>b</sup>	1,00 $\pm$ 0,37 <sup>cd</sup>	1,67 $\pm$ 0,29 <sup>bc</sup>	1,67 $\pm$ 0,37 <sup>bc</sup>
B-Naphthoflavone	9,44 $\pm$ 1,89 <sup>b</sup>	5,56 $\pm$ 0,56 <sup>ab</sup>	4,89 $\pm$ 2,02 <sup>abc</sup>	4,56 $\pm$ 0,90 <sup>ab</sup>	3,33 $\pm$ 0,41 <sup>ab</sup>
Naphthalene	8,38 $\pm$ 1,97 <sup>b</sup>	10,13 $\pm$ 2,66 <sup>a</sup>	6,13 $\pm$ 2,46 <sup>abc</sup>	6,63 $\pm$ 1,48 <sup>a</sup>	4,38 $\pm$ 0,63 <sup>a</sup>
Phenanthrene	12,78 $\pm$ 1,67 <sup>b</sup>	11,00 $\pm$ 1,58 <sup>a</sup>	6,78 $\pm$ 0,83 <sup>a</sup>	11,00 $\pm$ 1,12 <sup>a</sup>	7,33 $\pm$ 1,27 <sup>a</sup>
Benzo[a]Pyrene	9,00 $\pm$ 1,46 <sup>b</sup>	8,11 $\pm$ 1,25 <sup>a</sup>	5,78 $\pm$ 0,98 <sup>ab</sup>	6,67 $\pm$ 1,57 <sup>a</sup>	5,67 $\pm$ 1,53 <sup>a</sup>

<sup>abc</sup> Different letters indicate statistically significant differences (Tukey-Test  $p<0.05$ ) between treatments.

Table 3: Frequency of micronuclei and other nuclear abnormalities in peripheral blood of juvenile *A. metae* exposed to different concentrations of PAH after 72 h

Treatment	Micronuclei	Notched	Lobed	Blebbed	Binucleated
Control not injected	1,11 $\pm$ 0,48 <sup>a</sup>	2,33 $\pm$ 0,17 <sup>b</sup>	0,33 $\pm$ 0,17 <sup>cd</sup>	1,00 $\pm$ 0,33 <sup>c</sup>	0,27 $\pm$ 0,02 <sup>c</sup>
Solvent Control	1,89 $\pm$ 0,26 <sup>a</sup>	2,00 $\pm$ 0,37 <sup>b</sup>	1,00 $\pm$ 0,37 <sup>cd</sup>	1,67 $\pm$ 0,29 <sup>bc</sup>	1,67 $\pm$ 0,37 <sup>bc</sup>
B-Naphthoflavone	9,44 $\pm$ 1,89 <sup>b</sup>	5,56 $\pm$ 0,56 <sup>ab</sup>	4,89 $\pm$ 2,02 <sup>abc</sup>	4,56 $\pm$ 0,90 <sup>ab</sup>	3,33 $\pm$ 0,41 <sup>ab</sup>
Naphthalene	8,38 $\pm$ 1,97 <sup>b</sup>	10,13 $\pm$ 2,66 <sup>a</sup>	6,13 $\pm$ 2,46 <sup>abc</sup>	6,63 $\pm$ 1,48 <sup>a</sup>	4,38 $\pm$ 0,63 <sup>a</sup>
Phenanthrene	12,78 $\pm$ 1,67 <sup>b</sup>	11,00 $\pm$ 1,58 <sup>a</sup>	6,78 $\pm$ 0,83 <sup>a</sup>	11,00 $\pm$ 1,12 <sup>a</sup>	7,33 $\pm$ 1,27 <sup>a</sup>
Benzo[a]Pyrene	9,00 $\pm$ 1,46 <sup>b</sup>	8,11 $\pm$ 1,25 <sup>a</sup>	5,78 $\pm$ 0,98 <sup>ab</sup>	6,67 $\pm$ 1,57 <sup>a</sup>	5,67 $\pm$ 1,53 <sup>a</sup>

<sup>abc</sup> Different letters indicate statistically significant differences (Tukey-Test  $p<0.05$ ) between treatments.

process (Esmaeilbeigi *et al.*, 2021), it is interesting that in the present study at the exposure doses, lesions compatible with genotoxic damage were induced without evidence of irreversible alterations such as the presence of neoplasms, which is corroborated with the findings of Myers *et al.* (2008), in wild English sole (*Pleuronectes vetulus*) exposed *in situ* to sediments with high concentrations of BaP, where the induction of hepatic CYP1A was associated with the occurrence of neoplastic lesions and the formation of DNA adducts. In contrast, it is possible that the absence of neoplastic lesions in *A. metae* exposed to sublethal concentrations of BaP, PHE, and NaP, is related to the short period of exposure. Regarding the greater increase observed with those exposed to PHE, it has been reported in juvenile European bass (*Dicentrarchus labrax*), increases in nuclear abnormalities including the presence of micronuclei in specimens exposed for intraperitoneal route to 10 µg/g of PHE in sea bass after 3 and 6 months, which is related to biotransformation processes, led by CYP monooxygenase enzymes, which results in bioactivation into reactive metabolites that are more toxic than the precursor compounds (Reis-Henriques *et al.*, 2009; Karbassi and Heidari, 2015). Phenanthrene exposure in the neotropical guppy fish (*Poecilia vivipara*) was reported to alter behavior, at doses above 200 µg/L, that reduced prey capture, by modifications in swimming speed and associated trajectories that could reduce growth rates in the exposed fish (Torreiro-Melo *et al.*, 2015). In the liver of Senegal sole (*Solea senegalensis*), caught in a polluted estuary, EROD activity correlated with metabolites derived from the biotransformation of phenanthrene present in the water (Oliva *et al.*, 2014). In the current study, the exposure to PHE induced biotransformation by CYP1A that was evidenced by the increased in EROD activity (although it was not significant); likewise, it is important to highlight that erratic swimming was observed in phenanthrene-exposed fish during the development of the assay, this finding probably is related to the presence of toxic metabolites. In another study, bioactivation of toxic metabolites has been reported in the benthic species southern flounder (*Paralichthys lethostigma*) where relative biotransformation rates were slow for monohydroxylated metabolites of phenanthrene after 72 h intraperitoneal exposure to crude oil from the Deepwater Horizon spill (Pulster *et al.*, 2017). In addition, we cannot discard that others organ different that liver may exert biotransformation

process in the benthic and detritivorous cichlid *A. metae*. Instead, the induction of nuclear abnormalities in golden grey mullet (*Liza aurata*) during 16 h of exposure to concentrations of 0.1, 0.3, 0.9 and 2.7 µM PHE is reported, which led to a progressive increase in the presentation of abnormalities associated with increasing PHE concentrations (Oliveira *et al.*, 2007). PHE is also reported to induce genotoxicity in marine species such as the gastropod (*Morula granulata*), where DNA damage was demonstrated by comet assay from concentrations of 10 µg/L (Bhagat *et al.*, 2016). In turn, the presence of blebbed nuclei in *A. metae* erythrocytes exposed to PHE, BaP, and NAP, can be deduced that these abnormalities may be associated with a clastogenic effect of these PAH (Brzuzan *et al.*, 2006; Matsumoto *et al.*, 2006). Regarding the occurrence of binucleated cells it is considered as a cytotoxicity indicator (Çavaş and Ergene-Gözükara, 2005), due to this abnormality occurs by blocking cytokinesis during abnormal cell division (Yasui *et al.*, 2015); as evidenced in the specimens of *A. metae* exposed to PAH.

## CONCLUSIONS

The strength of the present study consisted in elucidate the effect of three representative PAH of environmental pollution on the response of different biomarkers in a native cichlid, since NAP and PHE have an environmental high frequency and BaP lead to high toxicity. The EROD activity in *A. metae* is a reliable biomarker of exposure to BaP. NAP, PHE, and BNF showed a non-significant increase in EROD activity in *A. metae*, although an elevated trend compared to controls was observed. This pattern is possibly due to two reasons, first, the low number of animals used that lead to the dispersion of the data distribution, and secondly, probably the liver is not the only organ capable of metabolized this PAH in this species. In the field studies, those issues should be considering, given that a complex mixture of contaminants including different PAH are found in the monitored water bodies. This study identified a greater genotoxic effect by PHE, even higher than fish exposed to BaP, this finding is very interesting considering that BaP is a recognized mutagenic agent and although PHE has fewer benzene rings, its biotransformation in this fish was possibly slower compared to BaP, NAP and BNF, in addition, it has been reported that PHE toxic metabolites are produced, which induced a greater cellular interaction

that was evidenced in the higher count of nuclear abnormalities. The behavior erratic swimming in fish exposed to PHE is a possible manifestation of the bioavailability and interaction with those metabolites. Finally, the presence of reversible alterations and the increase in cell proliferation in liver tissue in the groups exposed to PAH are associated to the sublethal doses and the short exposure used; however, it is not possible to discard that longer exposure could induce irreversible alterations that compromised the function of liver. In realist environmental scenarios a mixture of concentrations of xenobiotics such as NAP, PHE, and BaP are commonly found in natural waters that receive discharges of domestic and industrial wastewater. The results indicate that is relevant to evaluate the interaction of biomarkers because responses to individual xenobiotics can be attenuated in ecotoxicological studies when dealing with different classes of PAH. The usefulness of the intraperitoneal exposure route in the neotropical cichlid *A. metae* were confirmed, which in turn ratified this detritivorous fish as a bioindicator species for PAH pollution. From the analysis of the shown data, it is inferred that at concentrations close to those found in natural environments, exposed fish have the potential risk of developing alterations that impact both their health and also the one of the organisms associated with them. These results will serve as input to the environmental authorities for making regulatory decisions on the maximum PAH concentrations allowed in the freshwater bodies.

#### AUTHOR CONTRIBUTIONS

W. Corredor-Santamaría performed the literature review, experimental design, analyzed and interpreted the data, prepared the manuscript draft and manuscript edition. I.C. Calderón-Delgado performed the experiments, compiled the data and manuscript edition. Z. Arbeli designed the experiments, J.M. Navas performed the manuscript edition. Y.M. Velasco-Santamaría obtained the funding, performed experimental design, interpreted the data and manuscript edition.

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#### CONFLICT OF INTEREST

The author declares that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

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#### ABBREVIATIONS

°C	Celsius degree
µg	Microgram
µl	Microliter
µm	Micrometer
µM	Micromolar

$\mu\text{m}^2$	Square micrometer
%	Percent
<i>A. metae</i>	<i>Aequidens metae</i>
<i>ANH</i>	<i>Agencia Nacional de Hidrocarburos</i>
<i>ANOVA</i>	<i>Analysis of variance</i>
<i>BaP</i>	Benzo[a]Pyrene
<i>BNF</i>	$\beta$ -Naphthoflavone
<i>BW</i>	Body weight
<i>BSA</i>	Bovine serum albumin
<i>cm</i>	Centimeter
<i>CYP1</i>	Cytochrome P450, family 1
<i>CYP1A</i>	Cytochrome P450, family 1, subfamily A
<i>CYP1A1</i>	Cytochrome P450, family 1, subfamily A, polypeptide 1
<i>CYP1A3</i>	Cytochrome P450, family 1, subfamily A, polypeptide 3
<i>CYP1B1</i>	Cytochrome P450, family 1, subfamily B, polypeptide 1
<i>CYP1C</i>	Cytochrome P450, family 1, subfamily C
<i>DNA</i>	Deoxyribonucleic acid
<i>DO</i>	Dissolved oxygen
<i>DTC</i>	Degree of tissue Change
<i>DTT</i>	Dithiothreitol
<i>EDTA</i>	Ethylenediaminetetraacetic acid
<i>EROD</i>	7-ethoxy-resorufin-O-deethylase
<i>g</i>	Gram
<i>g</i>	Gravities
<i>h</i>	Hours
<i>H and E</i>	Hematoxylin and eosin
<i>HSI</i>	Hepatosomatic index
<i>KCl</i>	Potassium chloride
<i>Kg</i>	Kilogram
<i>IgM</i>	Immunoglobulin M
<i>L</i>	Liter
<i>M</i>	Molar
<i>mg</i>	Milligram
<i>Min</i>	Minute
<i>mM</i>	Millimolar
<i>MN</i>	Micronucleus
<i>NAP</i>	Naphthalene
<i>nm</i>	Nanometer
<i>PAH</i>	Polycyclic aromatic hydrocarbons

<i>pH</i>	Potential of hydrogen
<i>PHE</i>	Phenanthrene
<i>PMSF</i>	Phenylmethylsulfonyl fluoride
<i>SE</i>	Standard error
<i>SPSS</i>	Statistical Package for the Social Sciences
<i>Tris-HCl</i>	Tris hydroxymethyl aminomethane hydrochloride

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ORIGINAL RESEARCH PAPER

# Neural network-based classification of rock properties and seismic vulnerability

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## ABSTRACT

**BACKGROUND AND OBJECTIVES:** Soil or rock types in a region are often interpreted qualitatively by visually comparing various geophysical properties such as seismic wave velocity and vulnerability, as well as gravity data. Better insight and less human-dependent interpretation of soil types can be obtained from a joint analysis of separated and independent geophysical parameters. This paper discusses the application of a neural network approach to derive rock properties and seismic vulnerability from horizontal-to-vertical seismic ratio and seismic wave velocity data recorded in Majalengka-West Java, Indonesia.

**METHODS:** Seismic microtremors were recorded at 54 locations and additionally multichannel analyses of surface wave experiments were performed at 18 locations because the multichannel analyses of surface wave experiment needs more effort and space. From the two methods, the values of the average shear wave velocity for the upper 30 meters, peak amplitudes and the dominant frequency between the measurement points were obtained from the interpolation of those geophysical data. Neural network was then applied to adaptively cluster and map the geophysical parameters. Four learning model clusters were developed from the three input seismic parameters: shear wave velocity, peak amplitude, and dominant frequency.

**FINDINGS:** Generally, the values of the horizontal to vertical spectral ratios in the west of the study area were low (less than 5) compared with those in the southeastern part. The dominant frequency values in the west were mostly low at around 0.1–3 Hertz, associated with thick sedimentary layer. The pattern of the shear wave velocity map correlates with that of the horizontal to vertical spectral ratio map as the amplification is related to the soil or rock rigidity represented by the shear wave velocity. The combination of the geophysical data showed new features which is not found on the geological map such as in the eastern part of the study area.

**CONCLUSION:** The application of the neural network based clustering analysis to the geophysical data revealed four rock types which are difficult to observe visually. The four clusters classified based on the variation of the geophysical parameters show a good correlation to rock types obtained from previous geological surveys. The clustering classified safe and vulnerable regions although detailed investigation is still required for confirmation before further development. This study demonstrates that low-cost geophysical experiments combined with neural network-based clustering can provide additional information which is important for seismic hazard mitigation in densely populated areas

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## INTRODUCTION

Site amplification, rock and soil properties and other subsurface characteristics are among key parameters in building construction (Day, 2012). Site amplification indicates how the ground motion in an area increases when seismic waves from an earthquake traverse. The shaking of sites due to earthquakes varies depending on the type of rocks and thickness of sediment layers. Horizontal shaking resulting from shear and surface waves is considered to contribute more to damage than vertical shaking. Therefore, the horizontal-to-vertical spectral ratio (HVSr) of seismic microtremors at natural resonance (dominant) frequency can be considered as site amplification. Nakamura (2009) showed a strong correlation between HVSr values and building damages. Building damage is also related to the natural frequency. When a seismic wave arrives at a site, a building shakes considerably if the dominant frequency of the ground motion of the site is close to the natural frequency of the building (Kham et al., 2006). The dominant frequency has also suggested to be related to the thickness of the subsurface structure underneath a site (Nakamura, 2009). When an earthquake occurs, physical properties (e.g., stiffness) of the soils of a site where a building is situated play crucial role in the level of building damage (Fat-Helbary et al., 2019). The stiffness of soil or rock can be represented by shear wave velocity. In general, the shear wave velocity increases with the stiffness of rock. Studies on the impact of earthquakes in Dinar, Turkey showed that an alluvial flat basin with a low  $V_{s30}$  (average shear wave velocity over the upper 30-m soil profile) had the highest damage ratio (Kanli et al., 2006). Engineers use  $V_{s30}$  values to classify types of soil or rock in building standards (e.g., Ching and Winkel, 2018; Dobry et al., 2000). Rocks or soils with  $V_{s30}$  within 180–360 meter per second (m/s) and 360–760 m/s are classified as stiff and very dense, respectively (BSSC, 1997). Soil with  $V_{s30}$  less than 180 m/s are classified as soft and require a detailed investigation before buildings are constructed in a seismically active region. Shear wave velocity is also essential in the analysis of deterministic and probabilistic seismic hazards (Shreyasvi et al., 2019). For instance, the shear wave velocity at shallow depth is key input parameter in estimating ground motion. The  $V_{s30}$  values of sites can be determined by multichannel surface-wave analysis (MASW) using

active sources such as a sledgehammer (Park et al., 2007). Another approach to determining  $V_{s30}$  is based on the inversion of microtremor data recorded by a single three-component seismometer (Arai and Tokimatsu, 2004). Alternatively, the less invasive spatial auto-correlation (SPAC) method can be used to determine the average shear wave velocity at a certain depth (Chávez-García et al., 2005). Hollender et al. (2018) applied modified spatial auto-correlation (MSPAC) using three component seismic records to determine the shear wave velocity structure. The SPAC and MSPAC methods need to have ambient noise sources to randomly distributed to obtain reliable velocity estimation (Hollender et al., 2018). Thus, MASW is more reliable in determining the seismic wave velocity. The determinations of shear wave velocity, predominant period, and seismic amplification are parts microzonation studies. Such microzonation studies are often conducted because the more accurate studies based on *in-situ* penetration test are much more expensive. A geological structure can be also studied using other geophysical methods, e.g., ambient noise tomography (Ryberg et al., 2016), traveltime body wave tomography (Muksin et al., 2013a) and attenuation tomography (Muksin et al., 2013b), and using seismic refraction and reflection imaging. Compared with the tomography method, HVSr and MASW analyses are low-cost and robust methods for investigating the near-surface geological structures of densely populated areas. Several authors have combined both  $V_{s30}$  and HVSr data and qualitatively conducted a joint interpretation of soil or rock types and compared it with geology.

Asten et al. (2014) for example, suggested that the characteristics of  $V_{s30}$  were strongly correlated with HVSr. Stanko and Markušić (2020) investigated an empirical relationship between  $V_{s30}$  and HVSr (e.g., dominant frequency). The results showed that the relationship between the two parameters remains unclear with large standard deviation. There could be a relationship between  $V_{s30}$  and H/V values because both parameters represent physical properties of rocks. In microzonation studies, the correlation between the shear wave velocity and HVSr parameters is commonly investigated by visually comparing the geophysical parameters (Gallipoli and Mucciarelli, 2009). An area is defined as less vulnerable if the region is characterized by high  $V_{s30}$ , low H/V and high dominant frequency. However, the wide ranges

of geophysical values make us difficult to derive the characteristics of rocks more precisely and objectively from visual interpretation. The development of neural network methods offers the possibility of improving the analysis of geophysical data and advancing the interpretation of various parameters objectively. One can interpret various rock types and site amplification using a less human-dependent method based on pattern recognition of collocated geophysical data. Clustering different types of data has become more frequently used in geospatial data analysis (Jena *et al.*, 2020). For instance, the method of neural network has been used to correlate the shear wave velocity information with soil type microzonation based on the data pattern with visual interpretation (Nejad *et al.*, 2018). Stambouli *et al.* (2017) applied a neural network approach to acceleration and HVSR data to infer characteristics of site amplification. The latter mentioned examples make use neural network methods with supervised learning, where desired output such as soil type are specified by the user as a kind of target function during training. Here we present an exemplary feasibility study for the usage of self-organizing maps (SOM) in regional seismic vulnerability evaluation based on HVSR and shear wave velocity data. The SOM approach is different from other neural network method by application of unsupervised learning. This can provide an alternative, unbiased view on vulnerability classification, as the clustering is not influenced by any presumptions in supervised neural network methods. Common geophysical site proxies are derived and analyzed by the SOM method. The resulting classification map is interpreted and discussed based on comparison with pre-existing geological mapping and petrophysical signatures of the derived clusters. Similar approaches have been applied by Bauer *et al.* (2020) where a combination of different seismic parameters from tomographic inversion was used to identify and map the distribution of different lithologies. The objective of the study is to investigate the correlation among the site amplification (H/V peak ratio), dominant frequency and  $V_{s30}$  as well as to identify various geophysical signatures of soils or rocks from the data recorded in 2018 in Majalengka (West Java, Indonesia) by using the neural network method. The study area is a seismically active region surrounded by volcanic environment and highly populated city in West Java where earthquakes can occur along the subduction

zone and several active faults around the area (Fig. 1). The microzonation study in the study area was conducted as the region is planned to be developed in the near future. The result of neural network analysis is compared with the results of previous geological survey to demonstrate the feasibility of the approach. This study has been carried out in Majalengka, West Java in Indonesia in 2018.

#### *Geology and tectonic setting of west Java and Majalengka*

The tectonic setting of West Java illustrated in Fig. 1 is characterized by the northward movement of the Australian plate subducting beneath the Eurasian plate. The material subducted into the mantle is partially melted and rises to create several active volcanoes in west Java (Fig. 1). The combination of subduction, complicated plate motion, and crustal deformation triggers the presence of active faults in West Java including Cimandiri, Lembang, and Baribis (Fig. 1). These active faults and some volcanoes surround the district of Majalengka, which is populated by more than 1.1 million people, and hence earthquake risk in the region is high.

The closest active fault to Majalengka is the Baribis Fault (Fig. 1) extending from Subang to Majalengka (Supendi *et al.*, 2018). The Baribis Fault has recently generated earthquakes with magnitudes between Mw 2.0 and 4.7 (Pasari *et al.*, 2020). The Baribis Fault is a thrust fault accommodating the relative motion between the Java and Sunda block (Koulali *et al.*, 2017). Daryono *et al.* (2019) suggested that the maximum magnitude of earthquakes on the Baribis Fault could reach Mw 6.5-7.0 based on the fault length; i.e., 29 kilometer (km), whereas the recurrence time of large earthquakes was estimated to be 170-670 years. Another fault close to Majalengka is the Lembang Fault (Fig. 1), which accommodates the trench parallel component of the Australian-Eurasian convergence. The recent activities of the Lembang Fault are indicated by an M 3.3 earthquake reported by Meteorological, Climatological, and Geophysical Agency (BMKG) of Indonesia in 2011, as also suggested by Afnimar and Rasmid (2015). Further southwest, the Lembang Fault is offset by an active Cimandiri thrust fault (Supendi *et al.*, 2018). Based on the fault length, the maximum magnitude of an earthquake that can occur along the Cimandiri Fault is approximately M 6.0-7.0 (Irsyam *et al.*, 2017). Majalengka is surrounded

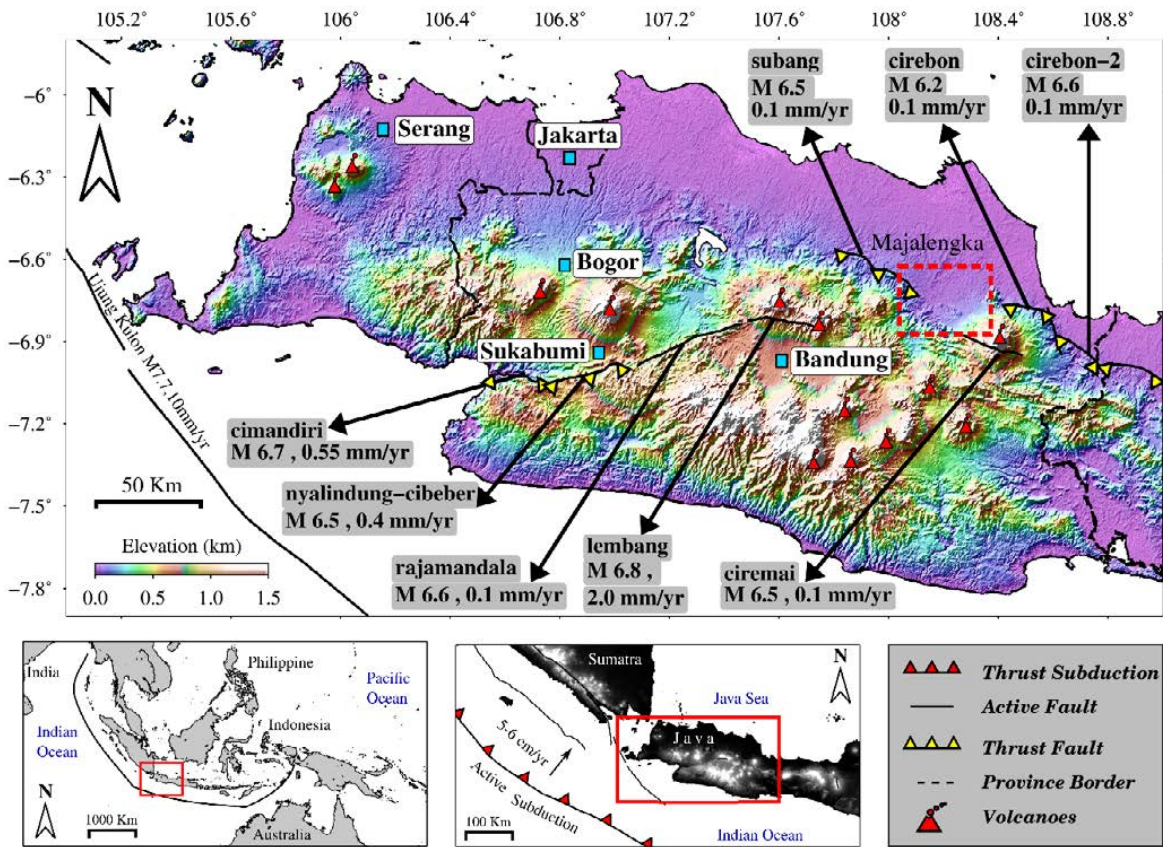


Fig. 1: (a) Geographical map of Indonesia and its surrounding with the study area (red square). (b) Seismicity map of West Java with the last decade's earthquake distribution; the volcano locations were obtained from Sparks *et al.* (2012). (c) The study area with the observation points of HVSR and MASW. The map is plotted using generic mapping tools (GMT) (Wessel *et al.* 2019); the fault lines were obtained from Irsyam *et al.* (2017).

by three main volcanoes: Tampomas in the west, Galunggung in the south, and Ciremai in the southeast of Majalengka as shown in Fig. 1. The Galunggung volcano erupted several times in 1822, 1894, 1918, and 1982–1983. Numerous fatalities were caused by the 1822 Galunggung eruption. The Ciremai stratovolcano was reported to erupt latest in 1937 without any fatality after the eruptions in 1772, 1775, and 1805 (Griffin, 2020). However, there is no report of the activity of the Tampomas volcano. The geology of Majalengka comprises tertiary sediments with intrusive and extrusive igneous rocks (Fig. 2). In the east, Majalengka generally comprises young volcanic products. The western part comprises Tjitjalong Formation and Aluvium. The Tjitjalong Formation

consists of conglomerate, breccia, and sandstone. Further south, Majalengka comprises shale members and sandstone in the Tjinambo Formation (Fig. 2). As the region is surrounded by volcanoes, Majalengka is characterized by high topography with an elevation of 19–857 m above sea level. Thus, this hilly area is vulnerable to secondary impacts of seismic activities, such as landslides.

## MATERIALS AND METHODS

Two geophysical experiments were performed to record 1) ambient seismic microtremor data and 2) controlled source MASW seismic data in Majalengka (West Java, Indonesia). The locations of the recording sites are marked with blue and red triangles in Fig.

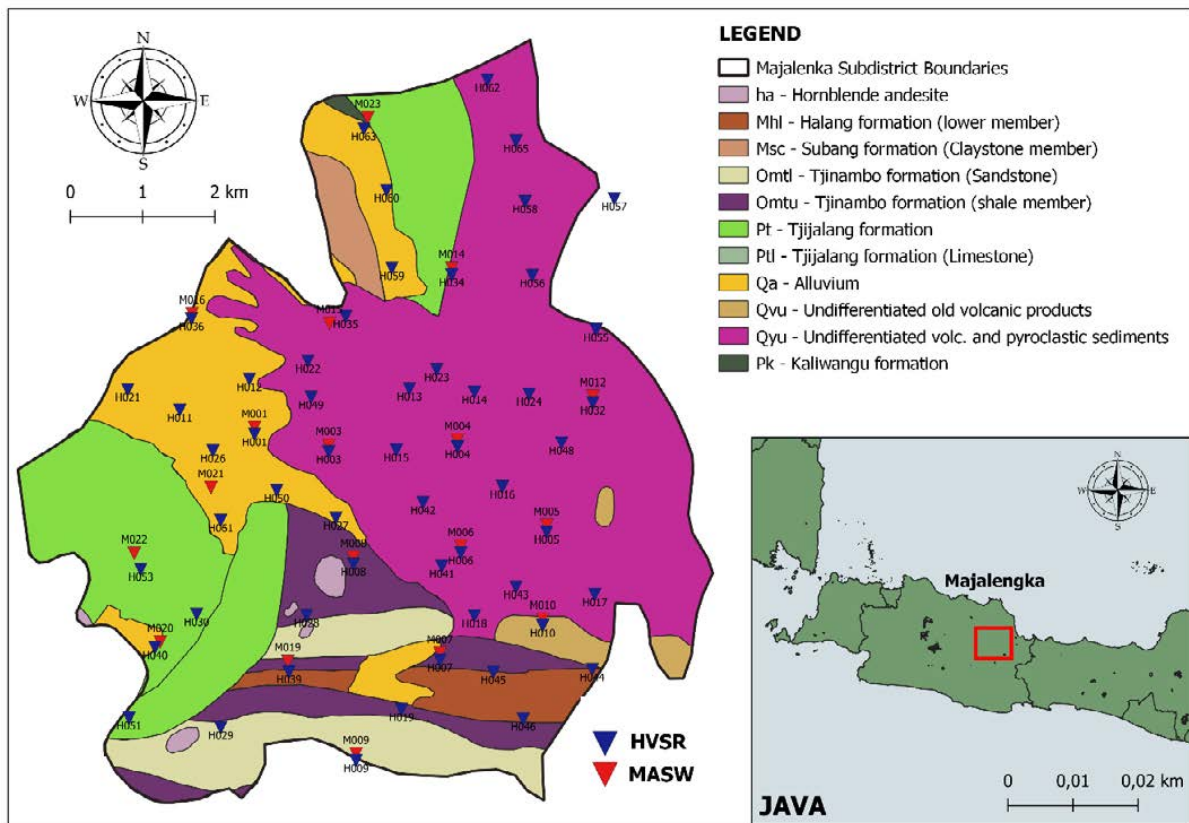


Fig. 2: Geology map of Majalengka (Modified from Djuri, 1995). The location of Majalengka on Java Island is shown in Fig. 1. The locations of the seismic experiments are indicated by red and blue triangles.

2. Particularly, the microtremor data were recorded at 54 sites indicated by blue triangles, whereas the MASW experiments, were performed at locations indicated by red triangles. Both deployments, seismic microtremor recordings and MASW experiments were relatively evenly distributed over the study area to interpolate and produce a representative map of the area.

#### *HVSr data derived from seismic microtremor survey*

The sources of seismic microtremors comprise the microseismic wave fields caused by human activities, the moon–earth interaction, and oceanic or tide-induced waves. The seismic microtremor measurements followed the procedure of [SESAME \(2004\)](#). A three-component short period seismometer, Lennartz Lite, equipped with a seismic

data logger was deployed for 30 min to record seismic microtremors at each location. Then, the time-domain recording at each location was subdivided into waveform segments of 50-s lengths. Waveform segments with transient noise, i.e., a sudden increase in the short-term-to-long-term average ratio, were excluded from the analysis. Thereafter, the fast Fourier transform was applied to the remaining 50-s waveform segments to transform the data from the time to frequency domain, and an algorithm from [Konno and Ohmachi \(1998\)](#) was applied for spectral smoothing. The horizontal and vertical components from all segments were stacked to obtain the averaged horizontal and vertical spectra for specific stations. After this stacking, HVSr was determined from the averaged spectra. The natural frequency ( $f_0$ ) was determined at the

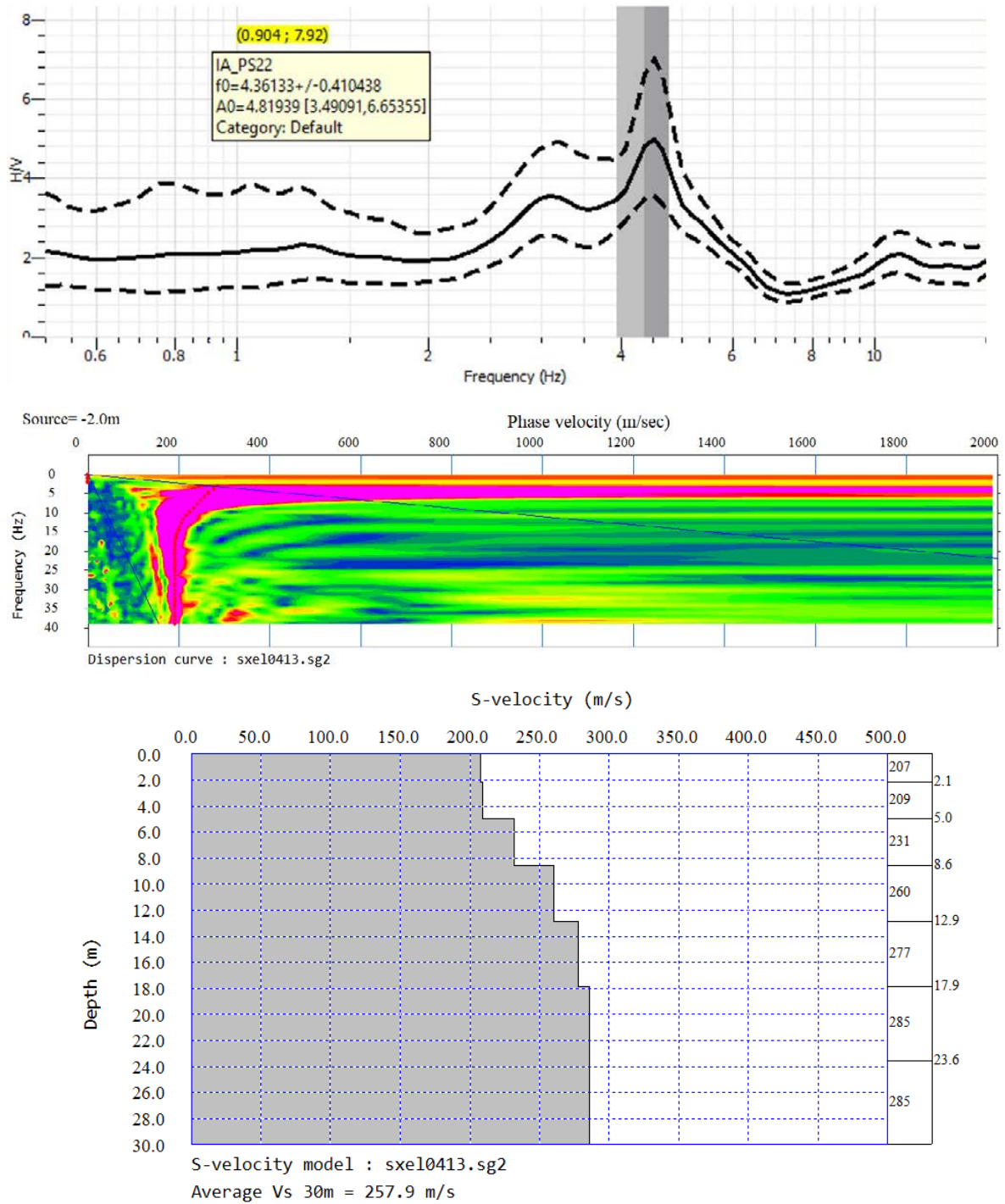


Fig. 3: HVSr of seismic microtremor at Point H020. The dominant frequency  $f_0$  is the frequency when H/V is maximum (H/V) (TOP). Dispersion curve showing the relationship between phase velocity and frequency at location M040 (MIDDLE). Shear wave velocity model derived from the dispersion curve (BOTTOM).

highest HVSr peak. The site amplification is given by the squared HVSr peak at the natural frequency. An example of the HVSr curve at Point H020 is shown in Fig. 3. The analysis procedure of HVSr is presented in Nakamura (2000). Next, the HVSr and dominant frequency values were interpolated to obtain two-dimensional maps of the geophysical signatures of the study area.

#### *Shear wave velocity modeling by using MASW*

The data acquisition for the shear wave velocity investigation was performed using the MASW method in Majalengka, West Java, Indonesia (indicated by red triangles in Fig. 2). A 2 kg hammer was used as the seismic source, and seismic waves were recorded by a 2-m interval of 24 geophones. All geophones were connected to a seismic digitizer. The 2-m interval was chosen to be comparable to the minimum surface wavelength to avoid undesired spatial aliasing. The seismic lines were set along a relatively flat 50 × 50-m<sup>2</sup> area to avoid significant changes in seismic recordings. The hammer was shot on the metal plate at one end of the seismic lines. The recordings were triggered by the hammer, and the seismic data were stored in the digitizer. The procedure of data acquisition for MASW followed the method described by Park *et al.* (1999). Then, the recordings from the forward and reverse shootings were transformed into a dispersion curve showing the relationship between the phase velocity of the Rayleigh wave and frequency (Fig. 3). Seismic surface waves with different wavelengths penetrate to different depths and propagate at different velocities. The dispersion curve is significantly influenced by S wave velocities for frequencies higher than 5 Hertz (Hz). Afterward, an iterative inversion method from Xia *et al.* (1999) was applied by imposing different S wave velocity models and layer thickness. Then, theoretical dispersion curves were calculated for different imposed models. The models (velocity and layer structure) were chosen as the final models when the theoretical and measured dispersion relation was closely fit. Examples of dispersion curves and resulting velocity models are shown in Fig. 3. As the inversion was applied for frequencies higher than 5 Hz, the consistently resolved depth range of the average velocity model was less than 30 m; hence, the velocity is called  $V_{s30}$  (Xia *et al.*,

2002). The analysis was performed to obtain one-dimensional velocity models for all locations. The values of geophysical data, including  $V_{s30}$ , HVSr, and dominant frequency between measurement points, were obtained from the data interpolation.

## RESULTS AND DISCUSSION

An area is classified as a high level of seismic vulnerability if the H/V value is high and the dominant frequency is low (Nakamura, 2009), and the  $V_{s30}$  value is low. An example for the seismic vulnerability analysis is shown for point H020 in Fig. 3. The bold line represents the HVSr result, whereas the dashed lines indicate the range of variations around the average curve. The maximum value of HVSr in the area of H020 is around 4.82. The dominant frequency (measured at the H/V peak) at Point H020 is 4.36 Hz which corresponds to a period of 0.23 s. The horizontal shaking due to an earthquake in the M005 area is suggested to be most amplified at frequencies of around 4.36 Hz. In general, the microtremor data are of good quality, so similar analyses could be performed for all 54 sites to determine the dominant frequency and H/V values. In addition, the MASW data are of good quality, supported by the fact that active sources and densely spaced multichannel receiver spreads were used in the experiments. Dispersion curves were determined (Fig. 3) and compared with theoretical curves to derive optimal 1D velocity models for each location.

The values of H/V peak, dominant frequency, and  $V_{s30}$  for all locations were interpolated to plot the Majalengka map. The H/V peak ratios show variations between 1 and 7 (Fig. 4a), whereas the dominant frequencies vary between 0.2 and 12 Hz (Fig. 4b). At some points, the two geophysical data correlate. The highest amplification indicated by the H/V value is the Point H053 region (Fig. 2), which is also constituted by lower values of the dominant frequency. Fig. 4c shows the  $V_{s30}$  map. The  $V_{s30}$  values in Majalengka were between 234 and 606 m/s. The  $V_{s30}$  map from Babakan to Majalengka (Fig. 4c) forms a pattern similar to the geology. Although Asten *et al.* (2014) suggested a strong correlation between  $V_{s30}$  and HVSr data, the comparison of the  $V_{s30}$ , H/V, dominant frequency values (Fig. 4) do not reveal clear correlation. Nevertheless, there was a clear anomaly in the east of the study area characterized by high H/V

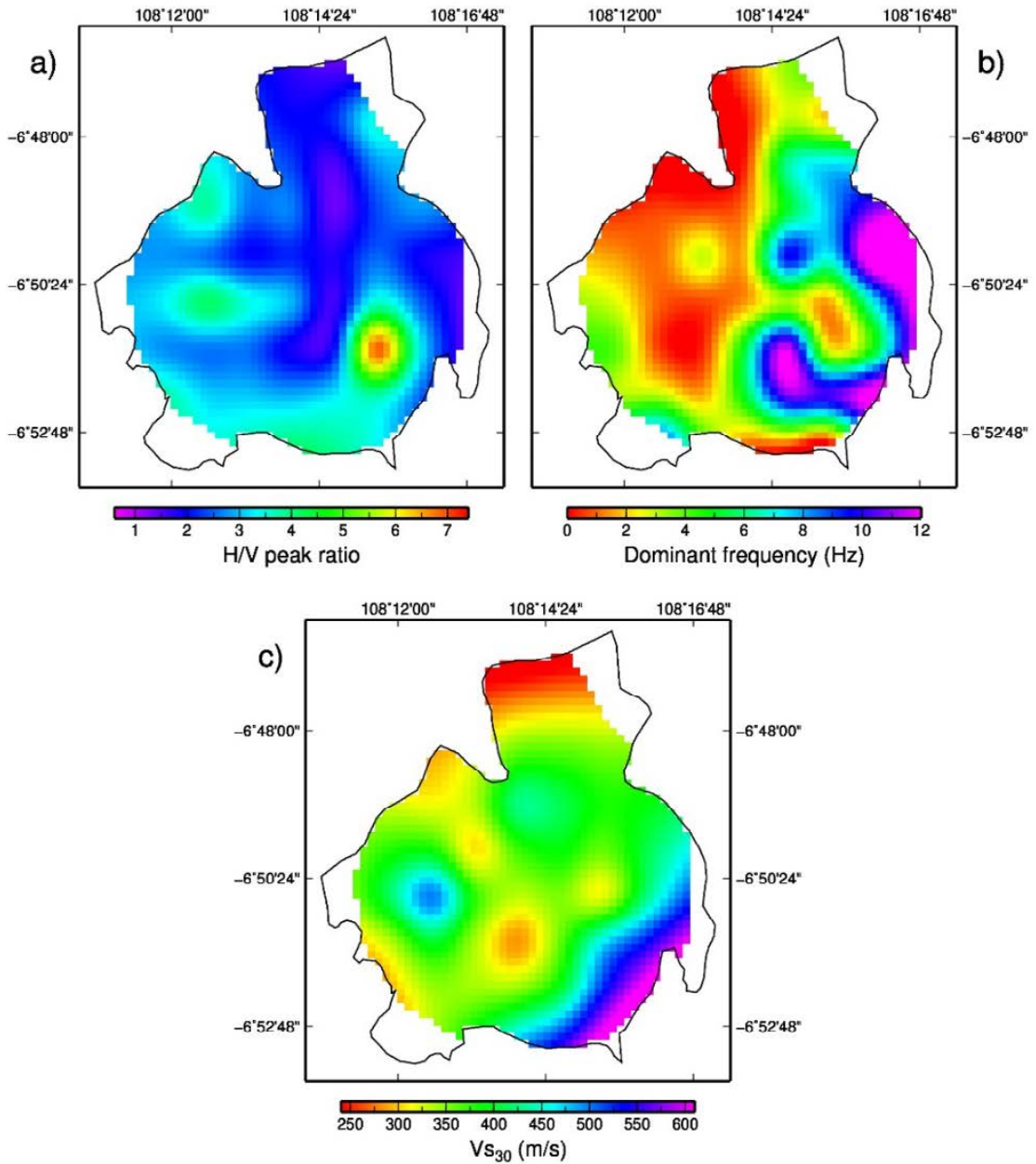


Fig. 4: Maps of interpolated seismic properties of (a) H/V peak ratio, (b) dominant frequency from ambient microtremor data, and (c)  $V_{s30}$  derived from the MASW data. The black outline shows the district boundaries of Majalengka

value (between 6–7) and low dominant frequency (less than 2 Hz). There was also no clear empirical relationship between dominant frequency and  $V_{s30}$  as suggested by [Stanko and Markušić \(2020\)](#). The three geophysical map is difficult to interpret based on

visual comparison. Therefore, the correlation among the three geophysical parameters was analyzed by neural network clustering. Thereafter, the results were interpreted by additionally considering the geology.

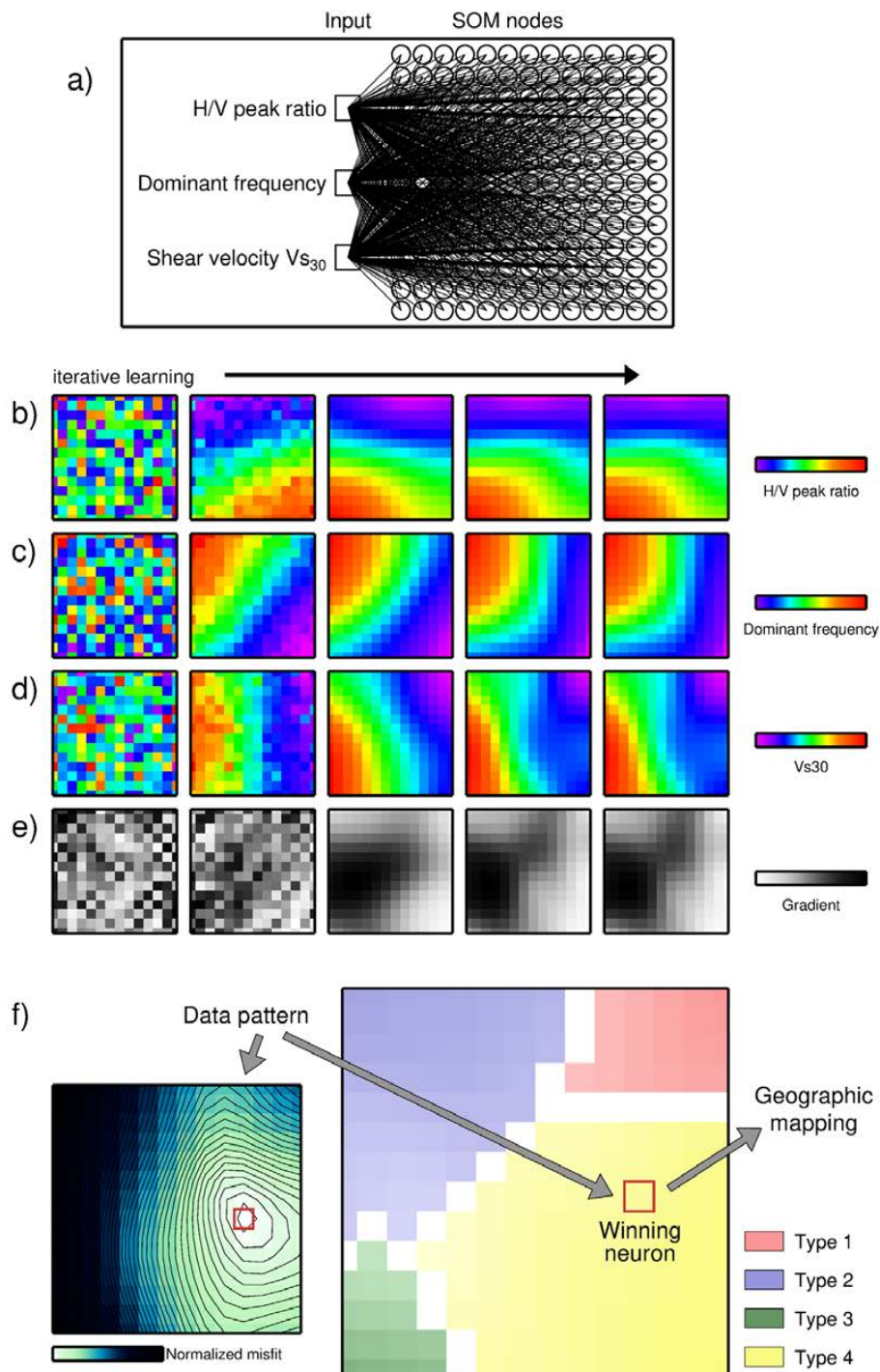


Fig. 5: (a) Design of the SOM which includes the input layer and a two-dimensional layout of SOM nodes. Evolution of the different components of the neural model vector (b-d) and the corresponding gradient function (e) during iterative learning. (f) Segmentation of the trained SOM. All input data patterns are classified based on the assignment of the winning neuron. The detection of the winning neuron is based on the evaluation of the normalized misfit function for a given data pattern vector. The associated color code is used in the geographic mapping of each input data pattern.

### Neural Network clustering

The seismic parameters derived from the microtremor and MASW data (H/V peak ratio, dominant frequency,  $V_{s30}$ ) were combined and analyzed using a neural network clustering approach. The general objective was 1) to identify clusters with similar seismic properties which are related with well-defined rock properties and vulnerability and 2) to map the geographic distribution of the clusters. Kohonen (1990) introduced the concept of self-organizing maps (SOM) which is based on unsupervised learning and Bauer et al., (2012) applied the method to geophysical data analyses. The SOM comprises an input layer and a two-dimensional arrangement of neurons (Kohonen, 1990). The input layer and neurons are fully connected (Fig. 5a). The values of H/V peak ratio, dominant frequency and  $V_{s30}$  from the inversion at given surface points are converted into three-component input vectors. Equally, each SOM neuron is represented by a three-component neural model vector. Before learning, the values of all neural model vector components are initialized with random numbers. During iterative learning, input vectors are randomly chosen and a learning rule is applied (Bauer et al., 2008). The so-called winning neurons with model vectors most similar to the input vector are modified to improve similarity between the input vector and the winning neural model vector. Such modification is also applied to the neighboring neurons of the winning neuron, but to a smaller degree. The effects of the iterative learning are illustrated in Fig. 5b–d. The model vector components show a random distribution over the SOM at the first iteration (left panels in Fig. 5b–d). With increasing iterations during learning, a systematic distribution develops across the SOM (right panels in Fig. 5b–d). Consequently, similar input vectors are associated with winning neurons at specific regions at the SOM. These specific clustering regions show small variations in the neural model vector components of neighboring neurons due to the learning rule. We use a gradient function to detect these regions based on small gradient values (Bauer et al., 2012). The separation of different clustering regions is indicated by large gradient values (dark colors in Fig. 5e). The gradient function is finally used for an automated definition of clusters in the trained SOM using an image processing technique called watershed segmentation (Bauer et al., 2020).

In this procedure, we firstly identify regions with low gradient (Fig. 5e). For each of those regions, the surrounding ridge with high gradient (watershed) is determined and used to define the outer boundary of the cluster at the SOM. The different clustering regions are color-coded where the gradient function is used to modify the color intensity (Fig. 5f). More insight into the application of the watershed segmentation algorithm is presented by example in Bauer et al. (2012). The gradient function is finally used for SOM automated segmentation (Bauer et al., 2020). The different clustering regions are color-coded, where the gradient function is used to modify the color intensity (Fig. 5f). Ultimately, for each winning neural vector, the related rock type with the corresponding color is used for plotting the geographical map.

### Joint analysis and interpretation

The result of the neural network analysis is a clustering of the data into groups with similar petrophysical properties (classification). The classification was based on the values of  $V_{s30}$ , H/V value and dominant frequency as shown in Fig. 6. The geological interpretation is based on (1) comparison of the geographic distribution with pre-existing maps, and (2) by consideration of the petrophysical signature of each cluster. The Neural Network clustering provided four types of near-surface rocks (Types 1–4) and vulnerability in Majalengka (Fig. 5f). The geographic distribution of Types 1–4 is shown in Fig. 6a. Each type is related to well-defined values of H/V peak ratio (Fig. 6b), dominant frequency (Fig. 6c), and  $V_{s30}$  (Fig. 6d). The rocks classified as Type 1 (red colors in Fig. 6) are characterized by low amplification with H/V peak ratios of around 2, low dominant frequencies (below 5 Hz), and low  $V_{s30}$  velocities (between 200 and 380 m/s). The Type 1 rocks comprise Alluvium and claystone with limestone beds of the Subang Formation (the geology of Majalengka in Fig. 2) and are mainly located in the northern part and some parts in the center of Majalengka. The Subang Formation and Alluvium are considered as stiff soils, which are consistent with  $V_{s30}$  velocities between 200 and 350 m/s. However, the HVSr and dominant frequency values of the areas comprising Type 1 rocks are low. A low dominant frequency is normally associated with a thick layer of rocks or sediments; therefore, the vulnerability is high. The Type 2 rocks (blue colors in Fig. 6) are characterized by moderate  $V_{s30}$ , low HVSr, and high dominant frequency values.

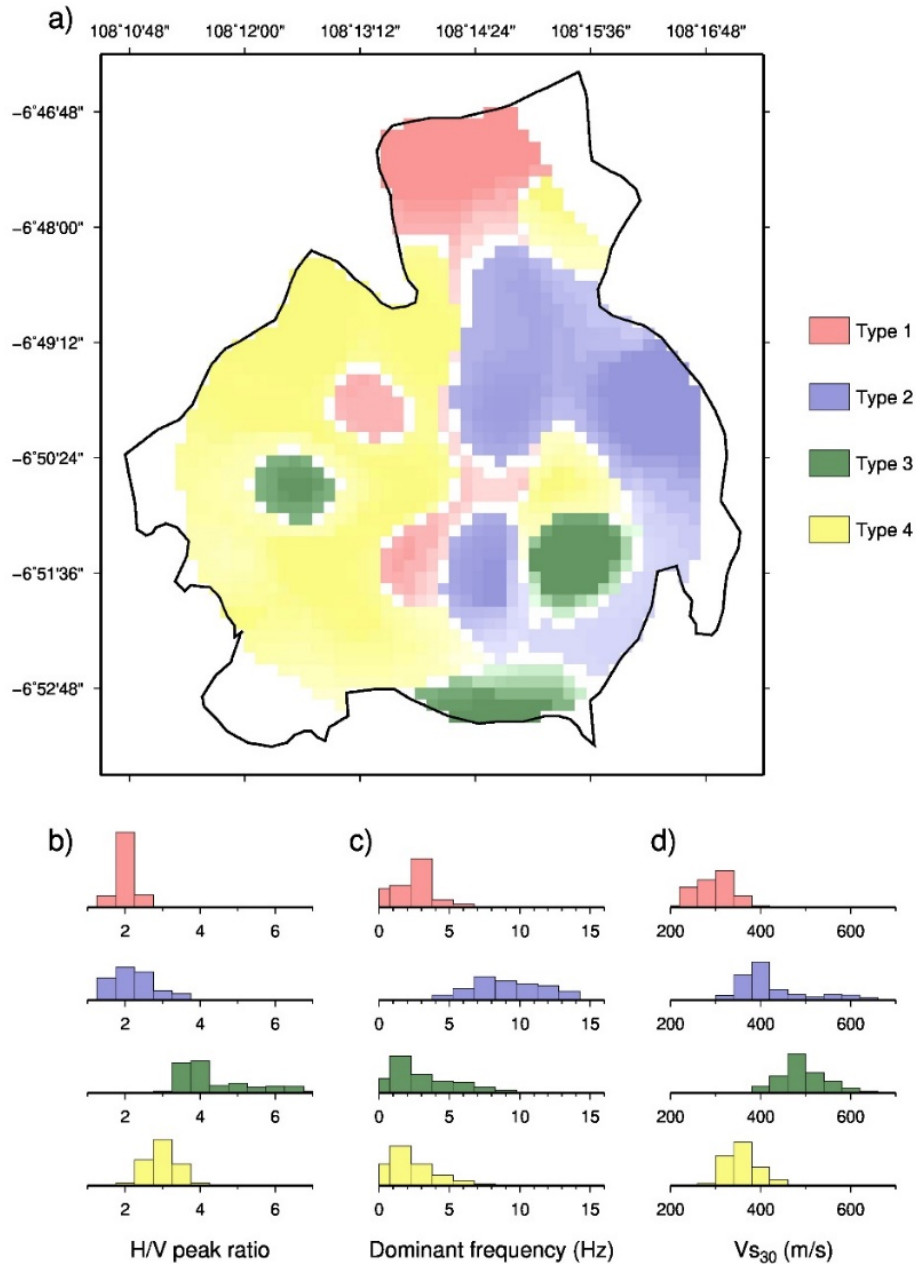


Fig. 6: (a) Geographic distribution of four types of near-surface rocks and vulnerability based on neural network clustering of petrophysical properties in Majalengka. Histograms of (a) H/V peak ratio, (b) dominant frequency, and (c) Vs<sub>30</sub> for Types 1–4.

The Type 2 rocks are situated mostly on the east side of Majalengka and comprise young volcanic products, e.g., andesitic and basaltic lava from the Tampomas and Ceremai volcanoes (Marliyani *et al.*, 2020). The geology of the Type 2 rocks agrees

with their geophysical properties. The seismic wave propagates faster within the volcanic rocks than within sedimentary rocks. Areas comprising dense rock are characterized by low amplification and high values of dominant frequency (Leyton *et al.*, 2013).

The geophysical and geological data reveal that sites within the cluster of Type 2 rocks are the safest areas from earthquake damage.

If we look at the geographic distribution of the Type 3 rocks (green colors in Fig. 6) and compare with the geological map from Djuri (1995), the type 3 cluster is associated with the Cinambo Formation, comprising sandstone and graywacke members. The cluster's areas comprise very dense soil or soft rock as indicated by high  $V_{s30}$  values above 400 m/s. Moreover, moderate-to-high amplification is indicated by the high H/V peak ratios of above 3, whereas the dominant frequencies are low. This combination of high H/V peak ratios and low dominant frequencies can be explained by a thick subsurface layer of the Cinambo Formation. Djuri (1995) estimated the thickness of the Cinambo Formation to be between 400 and 500 m. A tall building located on a low dominant frequency site, such as the thick Cinambo Formation is highly vulnerable as it responds sensitively to low frequency shaking. The Type 4 rocks (yellow colors in Fig. 6) cover the largest area and occur mainly in the western part of Majalengka. Comparison with the geological map indicates that Type 4 is associated with the Citalang Formation, comprising tuffaceous sandstone and conglomerate (Zaputlyaeva et al., 2020). The histograms in Figs. 6b–d show moderate amplification (H/V peak ratios of 2–4), low dominant frequencies, and moderate  $V_{s30}$  values (300–450 m/s) for this rock type. Based on this petrophysical and lithological characterization, the areas classified as Type 4 are relatively safe from seismic shaking and hence suitable for future development.

## CONCLUSION

Three key geophysical parameters,  $V_{s30}$ , H/V, and dominant frequency, were mapped in Majalengka based on a micro-zonation study. The eastern part of Majalengka is considered more vulnerable as H/V value is higher and the dominant frequency is lower than those in the western part. The  $V_{s30}$  values are generally between 220 and 400 m/s, except in a particular area in the east that is visually similar to the dominant frequency pattern. The pattern of  $V_{s30}$  correlates relatively well with the geology in a certain zone of the study area. Several possible geological features represented by the geophysical anomalies from the H/V, dominant frequency, and  $V_{s30}$  data

not found in the geological map are revealed. Visual observation shows that the western part of Majalengka is more vulnerable than the eastern part. Although the patterns of the three geophysical maps resulting from the conventional data analysis seem to relate to each other, it is difficult to classify different types of rocks and vulnerability in detail from visual observation. As an alternative approach for such vulnerability evaluation, the SOM method, an unsupervised NN-based approach, was applied to the three combined geophysical parameters in the form of data pattern vectors. The NN-based SOM method successfully defined four clusters associated with different rock types and related degrees of vulnerability in Majalengka derived from the three geophysical parameters. Each cluster correspond to a set of data pattern vectors representing similar underlying geophysical properties.

The characteristics of the clusters correlate well with pre-existing geological information, showing that the two largest clusters are those for the Type 2 rocks, in the east, comprising young volcanic products, such as andesitic and basaltic lava, and the Type 4 rocks, in the west, comprising tuffaceous sandstone and conglomerate. These two largest clusters are considered safe for future development because the areas are characterized by moderate-to-high  $V_{s30}$  values and low seismic amplification. Two smaller clusters comprising Types 1 and 3 rocks require more detailed studies before future developments are undertaken. These two smaller areas are characterized by low  $V_{s30}$  values of Alluvium (Type 1) and thick layers of sandstone with high amplification and low dominant frequency (Type 3). The application of the NN-based SOM method revealed several safe zones located within seismically vulnerable areas, e.g., Type 3 rocks located within Type 4 rocks in the western and eastern part of Majalengka, which are difficult to be distinguished by visual observation and comparison of the three geophysical maps. Another advantage of the NN-based SOM application is that a small cluster of rocks can be automatically identified inside a larger cluster as the Type 3 is situated inside the Type 4. Future research could include comparison with similar multiparameter interpretation approaches and additional involvement of vulnerability modeling.

## AUTHOR CONTRIBUTIONS

U. Muksin, the corresponding author, has contributed in supervising the second author in the data analysis HVSr and MASW, interpreted the results, and preparing the manuscript. E. Riana performed HVSr and MASW data analysis. A. Rudiyanto designed the field experiment and conducted field data acquisition as well as contributed in the HVSr and MASW data analysis. A.V.H. Simanjuntak prepared all the maps and figures and interpretation of the results. K. Bauer implemented and applied the neural network analysis and prepared related text and figures. M. Weber participated in the interpretation of the SOM results and manuscript preparation.

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## CONFLICT OF INTEREST

The author declares that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

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## ABBREVIATIONS

<i>1D</i>	1 – Dimension
<i>2D</i>	2 – Dimension
<i>3D</i>	3-component
<i>BMKG</i>	Badan Meteorologi Klimatologi dan Geofisika (Meteorological, Climatological and Geophysical Agency of Indonesia)
<i>cm/y</i>	Centimeter per year
<i>e.g</i>	Exempli gratia (for example)
<i>f<sub>0</sub></i>	Dominant frequency
<i>GMT</i>	Generic mapping tools
<i>H020</i>	HVSr observation point number 20
<i>H053</i>	HVSr observation point number 53
<i>Ha</i>	Hornblende andesite
<i>HVSr</i>	Horizontal to vertical spectral ratio
<i>H/V</i>	Horizontal over vertical
<i>Hz</i>	Hertz
<i>i.e.</i>	Id est (that is)
<i>kg</i>	Kilogram
<i>km</i>	Kilometer
<i>LTA</i>	Long-Term Average
<i>m</i>	Meter
<i>M</i>	Magnitude
<i>MASW</i>	Pearson correlation coefficient
<i>Mhl</i>	Halang formation (lower member)

<i>Msc</i>	Subang formation
<i>Mw</i>	Magnitude moment
<i>m/s</i>	Meter per second (velocity unit)
<i>m<sup>2</sup></i>	Meter square
<i>mm/y</i>	Millimeter per year
<i>M005</i>	MASW observation point number 05
<i>M024</i>	MASW observation point number 24
<i>NN</i>	Neural Network
<i>Pk</i>	Kaliwangu formation
<i>Pt</i>	Tjijalang formation
<i>Ptl</i>	Tjijalang formation with limestone
<i>Qa</i>	Alluvium formation
<i>Qmtl</i>	Tjinambo formation with sandstone
<i>Qmtu</i>	Tjinambo formation with shale
<i>Qvu</i>	Undifferentiated old volcanic products
<i>Qyu</i>	Undifferentiated volcanic and pyroclastic sediments
<i>s</i>	Second
<i>SPAC</i>	Spatial auto-correlation
<i>MSPAC</i>	Modified spatial auto-correlation
<i>STA</i>	Short-term average
<i>S wave</i>	Shear wave
<i>SOM</i>	Self-organizing maps
<i>Type 1</i>	First type of neural network results
<i>Type 2</i>	Second type of neural network results
<i>Type 3</i>	Third type of neural network results
<i>Type 4</i>	Fourth type of neural network results
<i>Vs</i>	Shear wave velocity
<i>Vs<sub>30</sub></i>	Shear wave velocity at depth of 30 m

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## ORIGINAL RESEARCH ARTICLE

Bioprocessing of organic wastes from poultry and bovine slaughterhouses as food substrate for *Hermetia illucens* larval developmentA.P. Luperdi<sup>1</sup>, S.S. Flores-Calla<sup>1,\*</sup>, X.J. Barriga<sup>1</sup>, V. Rivera<sup>1</sup>, I. Salazar<sup>1</sup>, P.L. Manrique<sup>1,2</sup>, J.E. Reátegui<sup>1</sup><sup>1</sup>Universidad Católica de Santa María, Postal address 04013, Perú<sup>2</sup>Instituto de Investigación y Desarrollo para el Sur, Postal address 04018, Perú

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## ABSTRACT

**BACKGROUND AND OBJECTIVES:** In the meat industry, inefficient management of organic waste exists, therefore the study aims to evaluate different bovine and poultry organic residues as food substrates during larval development of the black soldier fly, such as a sustainable alternative to obtain high protein meal.

**METHODS:** The research evaluates the use of organic waste from cattle and poultry slaughterhouses, as food substrate for black soldier fly larvae, including raw beef blood T1, raw beef viscera T2, cooked beef blood T3, cooked beef viscera T4, raw chicken viscera T6 and cooked chicken viscera T7; further, as a control measure balanced feed (7 treatments and 5 replicates). Larvae were fed for 5 days and processed to make meal by drying and grinding; evaluating mortality, weight, size, proximal chemical composition, and apparent digestibility to determine the most viable substrate, analyzing effects and significance by multifactorial ANOVA and Kruskal-Wallis.

**FINDINGS:** The results show Mortality ( $F = 917,81$ ,  $p < 0,0001$ ): T1 y T3 with  $76,40 \pm 2,86$  (%) ( $F = 917,81$ ,  $p < 0,0001$ ), following T6 with  $69,67 \pm 4,55$ %, T7 with  $24,00 \pm 3,48$ %, T2 with  $4,60 \pm 1,92$ %, T5 y T4, both with  $4,20 \pm 2,00$ %. Weight ( $F = 825,62$ ,  $p < 0,0001$ ): T2 with  $1,78 \pm 0,22$  gram outperformed the control T5 ( $1,76 \pm 0,50$  gram), T4 with  $1,45 \pm 0,06$  g and T7 with  $1,66 \pm 0,07$  gram. Size ( $F = 248,95$ ,  $p < 0,0001$ ): T5 with  $16,03 \pm 0,34$  mm, T2 with  $15,86 \pm 0,22$  mm, T4 with  $14,72 \pm 0,35$  mm and finally,  $14,51 \pm 0,14$  millimeter in T7. Proximal chemical analysis of crude protein and fat: T2 resulted in the following results 50,81 % and 21,88 %, T4 with 53,90% y 15,04%, T7 with 42,63 % and 32,03%, and T5 con 41,1 % and 19,55%, respectively. Digestibility: T5 with 20,39%, T2 with 12,66%, T4 with 10,61% and T7 with 5,97%. T2 raw beef viscera were determined to be the most viable substrate, followed by T4 cooked beef viscera and T7 cooked chicken viscera.

**CONCLUSION:** Testing the effectiveness of cattle viscera as substrate, the experimental data presented may help design a process for an effective treatment method for slaughterhouse waste, which might benefit developing nations in managing their waste effectively, generating high protein meal, with the potential for a circular bioeconomy.

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## INTRODUCTION

Globally, waste generation is expected to reach 3.4 billion tonnes by 2050, currently, 44% of total accumulated waste comprises biodegradable materials, with a higher proportion in low to middle-income countries; most of these are disposed of in landfills (37%) or open dumps (33%) (Lopes et al., 2022). These forms of biodegradable waste disposal are considered important threats to the environment, due to the greenhouse gases (GHG) released into the atmosphere and the contamination of soil and water with toxic compounds, among other factors (Koda et al., 2017). A promising method for treating biodegradable waste that could contribute to the current challenge; black soldier fly (BSF) larvae treatment represents an efficient and economical option for recycling biological matter (Gold et al., 2018; Salam et al., 2022). BSF, *Hermetia illucens* (Diptera: Stratiomyidae), is a generalist saprophytic detritivorous species that colonize a wide variety of matter (Guo et al., 2021; Morais, 2020). Its potential is related to the biological characteristics of its larval stage (Giannetto et al., 2020), capable of reducing 60 to 90 percent (%) of the organic matter volume of substrates (Morales Quintana, 2021). *Hermetia illucens* presents a bioconversion rate of 140 %, with larvae consuming their own weight in food every 12 h (Makkar et al., 2014; Oonincx et al., 2015), accumulating around 40% or more as protein (Ebenezezar et al., 2021). This high protein concentration and the content of other nutrients such as fatty acids, pigments, vitamins, and minerals, allow its inclusion in poultry, livestock, and aquaculture diets (El-Hack et al., 2020; Giraldo J., 2019; Liland et al., 2017). It is important to note that in the adult stage, its jaw is atrophied and it does not need feed to produce viable offspring, being easy to control (Giraldo J., 2019). In addition, BSF is not a vector for the spread of diseases (Singh and Kumari, 2019) compared to other insects, favoring safe breeding and its application in biotechnologies. Like other animal species used for feeding, the nutrient content of biowaste is assumed to have the greatest influence on yield (Gold et al., 2020; Tinder et al., 2017). Biowaste nutritional quality is determined by factors including the density (humidity), proportion, and type of nutrients they contain, as the sum of macronutrients, organic matter, protein, non-fibrous carbohydrates (NFC), fiber, and lipids (Barragán-

Fonseca et al., 2018; Gold et al., 2018). Biowaste nutritional quality like the sum of macronutrients, organic matter, protein, non-fibrous carbohydrates (NFC), fiber quantity (cellulose, lignin, hemicellulose), and lipids, is important to determine the level of nourishment provided (Barragán-Fonseca et al., 2018; Gold et al., 2018; Gold et al., 2020; Tinder et al., 2017). BSF feeding experiments suggest that proteins, NFC, and lipids are highly digestible and therefore their supply improves performance (Barragán-Fonseca et al., 2018; Beniers and Graham, 2019). Fiber, on the contrary, is less digestible and tends to decrease larval growth rates (Liu et al., 2018). Faced with these different nutritional conditions, fly larvae adjust their growth rate and nutrient accumulation, with the primary goal of amassing sufficient reserves to complete the non-feeding life stages of metamorphosis and adulthood (Danielsen et al., 2013). In this insect-based treatment, biodegradable waste is converted into products like larval biomass rich in lipids and proteins (Lalander et al., 2019) that can be used in animal feed; and in residues like exoskeleton with chitin processing (Siddiqui et al., 2022), frass considered fertilizer (Beesigamukama et al., 2020; Siddiqui et al., 2022; Xiao et al., 2018), as valuable products are generated, this technology fulfills with the principles of a circular bioeconomy, in which the waste from one process becomes the resource in another (Slorach et al., 2019). There are different organic wastes of high environmental impact that have the ability to be used as food substrate for *Hermetia illucens*; this is the case of waste from the meat industry, which generates liquid effluents from the washing of livestock and poultry, bleeding area, removal of hides, fur, feathers, viscera and cleaning operations, resulting from the processing of meat. Blood and viscera represent approximately 25% of the total weight of a 1000 kg carcass, generating effluents with raised amount of organic compounds High biochemical oxygen demand BOD 520 milligram per liter (mg/L)), as well as suspended solids 1728 mg/L, and a high concentration of phosphorus 63 mg/L, a parameter related with matter putrefaction (Ruiz Sánchez, 2019), exceeding by far MPL (250 mg/L, 300 mg/L, 40 mg/L, respectively) (Salas and Condorhuamán, 2008). Therefore, the objective of this study, is the conversion of cattle and poultry slaughterhouse wastes into high protein meal, taking advantage of *Hermetia illucens* larval development,

which reduces organic matter and treatment costs. The overall findings of this study could be very helpful to the scientific society, and animal and meat industries, providing baseline knowledge and guidance on how BSF treatment facilities may systematically operate using biowastes of varying types, eventually, low-cost protein food will be produced by giving added value and making the production sustainable. This study has been carried out at the Catholic University of Santa Maria, Arequipa, Peru in 2019.

## MATERIALS AND METHODS

For the experimental tests, aseptic conditions, sterilized materials, and supplies were used, applied an autoclave (Ecoshel CVQ-B100L, Mexico).

### Obtaining Black soldier fly

Oviposition units were obtained from adult black soldier fly BSF, *Hermetia illucens*, reared under a controlled environment from the pilot plant of the Catholic University of Saint Mary, located at Fundo "La Católica", district of Pedregal, Province of Caylloma, Arequipa region, Peru. Geographically located at South Latitude 16° 20' 08.35'', West Longitude 72° 09' 08.56'' at an altitude of 1498 meters above sea level (m.a.s.l.), (MAP, 805. Pampa de Majes, Ubigeo Code 040520).

### Larval growth on different substrates and meal production

Blood and beef viscera were collected as organic waste from "Santa María de la Colina" metropolitan animal slaughterhouse, likewise, chicken viscera from "Gamboa" poultry processing center, both located in Majes city; the biomass was packaged at 4 °C for 24 h and brought to the experimental temperature prior to each feeding experiment, to avoid external conditions that could affect the feeding. All viscera were processed in a mincer (Thomas TH-9010 400 w, Germany) to get a uniform puree and facilitate the *Hermetia illucens* larvae consumption. Half wastes were cooked for 5 minutes on a hot plate electric stove (Star JX – 6121B, Spain). Thereby 6 food substrates for the larvae were obtained: raw beef blood T1, raw beef viscera T2, cooked beef blood T3, cooked beef viscera T4, raw chicken viscera T6, and cooked chicken viscera T7; also a standard balanced feed (50 % bran, 20% corn meal and 30% alfalfa mixture) T5; moisture content

at 60% was monitored, adding solid standard feed or water (purified using Reverse Osmosis Water Purifier PREC PRO7/D1 – 100, Peru). A growth system was established in a controlled environment at 28°C; with a minimum development temperature of 19°C (Holmes *et al.*, 2016) and 60 % humidity (Purkayastha and Sarkar, 2022), insects are ectothermic organisms that regulate their physiological functions according to environmental conditions (Abram *et al.*, 2017); applying 7 treatments and 5 replications for each one, 35 experimental units in total. In the oviposition unit, hatched BSF eggs at larval stage 1 were carefully collected in porous cardboard structures called eggies, approximately 10,000 to 15,000 eggs were sown in moist balanced feed; 5 days later, once the secondary larvae had reached stages 2 to 3, 500 g of larvae were randomly transferred to individual trays containing 3 kg of each feed substrate (T1 – T7). Then, after 5 days of treatment, larvae were in larval 5 and prepupal stage, the optimal point for food processing (Lalander *et al.*, 2018), characterized by whitish color and soft exoskeleton. Larvae were sifted and several parameters were registered as weight using a digital electronic balance (ABranddeals SF-400, Mexico) and size measured using an electronic vernier (Uberman RM813, Chile). Moreover, humidity (H), mortality (M), total dry matter (TDM), crude protein (CP), ethereal extract (EE), ash (A), crude fiber (CF), nitrogen-free extract (NFE), volatile organic matter (VOM) and apparent digestibility (AD) were evaluated in the percentage of dry matter (%DM), according to The Association of Official Analytical Chemists (AOAC) International protocols, before and after growth, to control the organic residues degradation. At the end of the larval growth period, larvae were manually separated, dried in a hot air dehydrator (Own manufacturing, Peru) at 70 °C for 5 h, and pulverized in an electric mill (Own manufacturing, Peru) to obtain larvae meal, which was characterized according to the AOAC protocol (Feldsine *et al.*, 2002).

### Statistical analysis

Treatment effects were analyzed by multifactorial ANOVA, using substrate type and time as main variables. Means and standard deviations were calculated from the data obtained. The Kruskal-Wallis test was applied to determine the significance ( $\alpha = 0.05$ ) between treatments.

## RESULTS AND DISCUSSION

All the experimental treatments were performed with 5 repetitions, considering statistical analysis.

### Waste degradation

Table 1 shows the quality parameters of each waste substrate at the beginning and end, being the most outstanding, CP levels of T3 with 89.35%, while the control T5 only contains 12.83 %, explained by its high fiber composition. T6 and T7 raw and cooked chicken viscera respectively have 26.23 % and 25.79 % but a low level of EE indicating a low level of CF. The content of dry matter, protein, lipids, ash, and

fiber also varied among the wastes. Wastes have an amount of highly digestible lipids and protein and will have a greater impact on development up to prepupae (Barragán-Fonseca *et al.*, 2018; Beniers and Graham, 2019).

### Larval growth on different substrates

Weight and size analyses showed a significant difference ( $P < 0.0001$ ) over 5 days and between treatments. Fig. 1 shows the weight through 5 days, it was observed that T2 ( $1.78 \pm 0.02$  g) and T5 ( $1.76 \pm 0.05$  g) are practically equal, demonstrating their effectiveness, followed by T4 ( $1.45 \pm 0.06$  g) and

Table 1: Comparison of initial and final nutritional parameters for each of the seven different treatments

Treatments nutritional parameters	T1		T2		T3		T4		T5		T6		T7	
	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final
TDM (%)	35.73	20.56	33.17	43.55	21.90	45.75	29.13	38.15	31.30	27.75	38.73	27.79	43.50	72.46
H (%)	64.27	79.44	66.83	56.45	78.10	54.25	70.87	61.85	68.70	72.25	61.27	72.21	56.50	47.54
CP (%DM)	54.57	48.60	65.17	51.88	89.35	36.07	57.44	59.59	12.83	14.69	26.23	26.88	25.79	24.25
EE (%DM)	0.09	2.01	6.38	5.22	0.53	0.50	2.89	2.27	1.06	1.59	31.55	25.76	25.93	22.59
A (%DM)	3.85	8.54	7.46	6.81	3.65	5.11	6.11	8.34	9.27	6.18	3.95	4.38	4.40	5.12
CF (%DM)	4.57	18.81	2.03	3.66	0.06	7.72	0.42	2.44	22.52	8.56	4.64	4.74	6.03	8.33
NFE (%DM)	36.92	2.04	18.95	32.44	6.41	50.61	33.14	27.37	54.33	68.98	33.63	38.24	37.84	39.70
VOM (%DM)	96.15	91.46	92.54	93.19	96.36	94.46	93.89	91.66	90.73	93.82	96.05	95.62	95.60	96.05

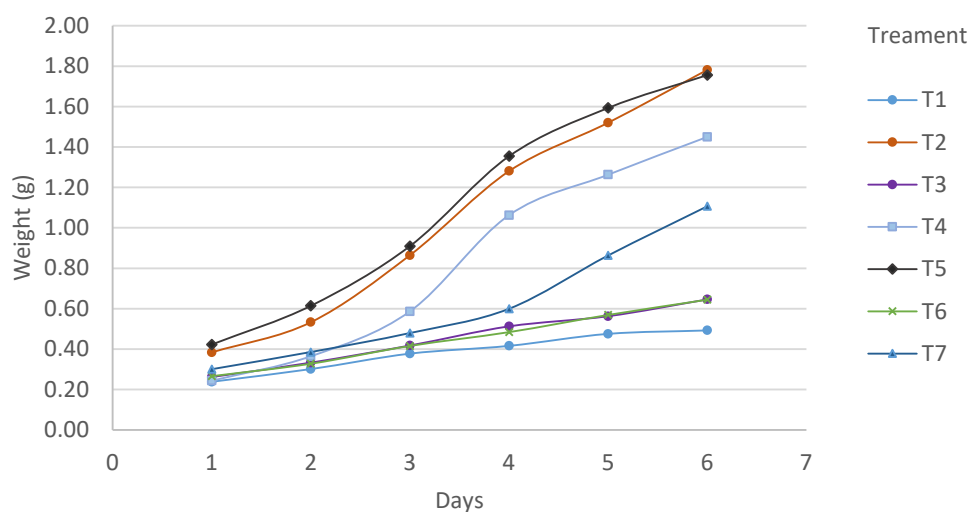


Fig. 1: Weight of *Hermetia illucens* larvae for each treatment over time. Larval growth system (T1: raw beef blood, T2: raw beef viscera, T3: cooked beef blood, T4: cooked beef viscera, T5: control (balanced feed), T6: raw chicken viscera, and T7: cooked chicken viscera)

Table 2: ANOVA *Hermetia illucens* larvae weight at day 5

Source	Sum of Squares	Gl	Half-square	F	P
Substrate	21.7665	1	21.7665	825.62	0.0000
Cooking	0.071286	1	0.071286	2.70	0.1021
Interaction	5.28469	1	5.28469	200.45	0.0000
Residue	4.11277	156	0.0263639		
Total (correct)	31.265	159			

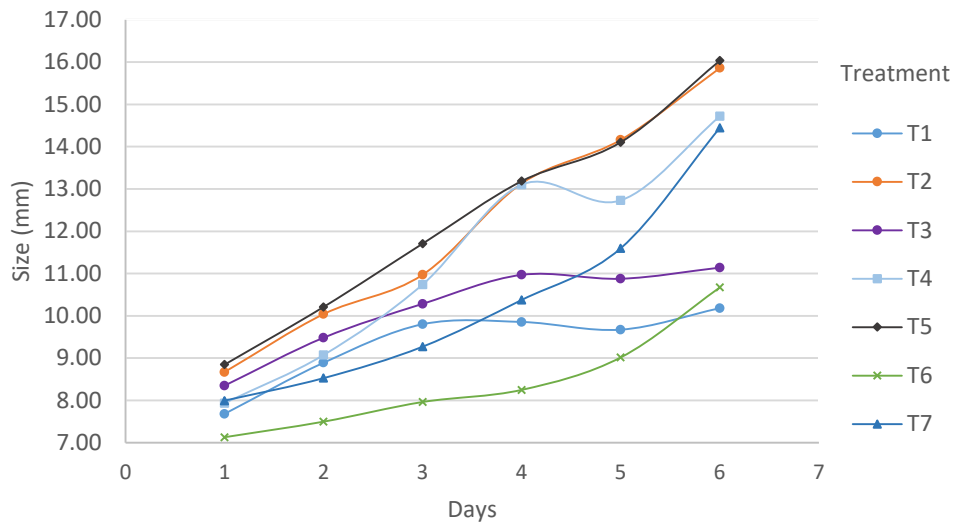


Fig. 2: Size of *Hermetia illucens* larvae for each treatment over time. Larval growth system (T1: raw beef blood, T2: raw beef viscera, T3: cooked beef blood, T4: cooked beef viscera, T5: control (balanced feed), T6: raw chicken viscera, and T7: cooked chicken viscera).

Table 3: ANOVA *Hermetia illucens* larvae size at day 5

Source	Sum of Squares	Gl	Half-square	F	P
Substrate	273.49	1	273.49	248.95	0.0000
Cooking	68.037	1	68.037	61.93	0.0000
Interaction	232.012	1	232.012	211.19	0.0000
Residue	171.377	156	1.09857		
Total (correct)	697.911	159			

T7 ( $1.06 \pm 0.07$  g), and finally T1 ( $0.49 \pm 0.04$  g), T3 ( $0.65 \pm 0.05$ g), T6 ( $0.64 \pm 0.05$  g). Gold *et al.* (2020) presented data about low-weight larvae in the same stage fed with substrates like Mill by-products (0.17 g), Cow manure (0.06 g), Human feces (0.24 g), and Poultry slaughterhouse waste (0.16 g). Similar results, Zhou *et al.* (2013) tried with Poultry manure (0.15 – 0.26 g), Cow manure (0.07 – 0.15 g) and Human faeces (0.07 - 0.30 g). In addition, Tinder *et al.* (2017) studied millings and brewery side streams (0.08 – 0.29 g).

In Table 2 can be observed the type of substrate used having an influence on weight ( $F = 825.62$ ,  $P < 0.0001$ ), but not on whether the substrate was raw or cooked ( $F = 2.70$ ,  $P > 0.0001$ ). On the other hand, there was an interaction between the type of substrate and the cooking process ( $F = 200.45$ ,  $P < 0.0001$ ).

Fig. 2 shows evolution profiles of BSF size, T2 ( $15.86 \pm 0.22$  mm) remains very close to T5 ( $16.03 \pm 0.34$  mm) with little difference, the next profile is

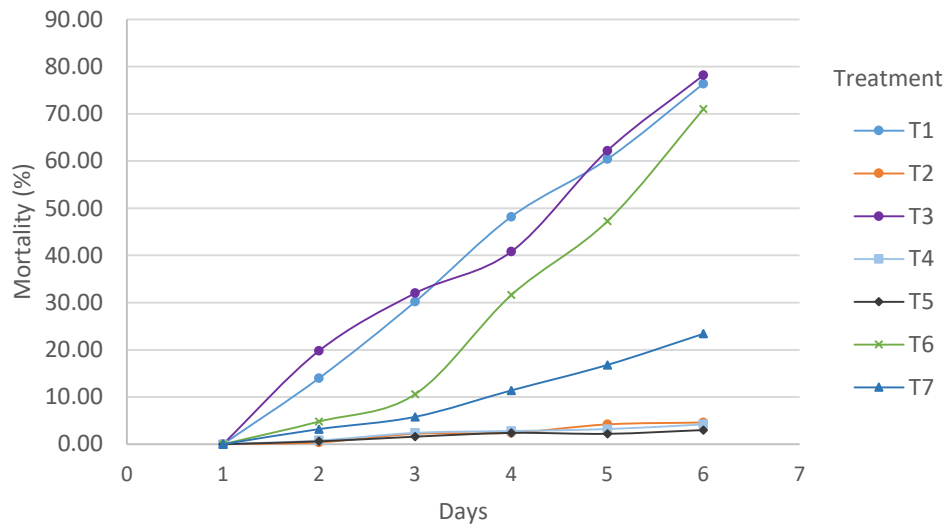


Fig. 3: Mortality of *Hermetia illucens* larvae for each treatment over time. Larval growth system (T1: raw beef blood, T2: raw beef viscera, T3: cooked beef blood, T4: cooked beef viscera, T5: control (balanced feed), T6: raw chicken viscera, and T7: cooked chicken viscera)

Table 4: ANOVA *Hermetia illucens* larvae mortality at day 5

Source	Sum of squares	Gl	Half-square	F	P
Substrate	67522.0	1	67522.0	917.81	0.0000
Cooking	19895.0	1	19895.0	270.43	0.0000
Interaction	19210.0	1	19210.0	261.12	0.0000
Residue	11476.7	156	73.5684	-	-
Total (correct)	110284.0	159	-	-	-

T4 ( $14.72 \pm 0.35$  mm) with small stagnation due to the digestibility of the larvae. T7 ( $14.51 \pm 0.40$  mm) has a very slow growth below the rest in the first 4 days. Finally, T1 ( $9.98 \pm 0.12$  mm), T3 ( $11.14 \pm 0.35$  mm) and T6 ( $10.67 \pm 0.40$  mm). In addition, it was shown in Table 3 that substrate type ( $F = 248.95$ ,  $P < 0.0001$ ), cooking ( $F = 61.93$ ,  $P < 0.0001$ ) and the interaction between the two ( $F = 211.19$ ,  $P < 0.0001$ ) did influence BSF size and growth.

As shown in Fig. 3, T1 and T3 have the highest mortality, reaching  $76.40 \pm 2.86\%$ , followed by T6 with  $69.67 \pm 4.55\%$ . Likewise, T7 with  $24.00 \pm 3.48\%$ . T2 with  $4.60 \pm 1.92\%$ , T4, and T5 with  $4.20 \pm 2.00\%$ . Some authors indicate this result in % survival units (% complementary to mortality), Gold et al. (2020) use as biomass mill by-products, human feces, cow manure, and poultry slaughterhouse waste, with results from 1% to 10% and were not significantly different between the types of biowaste. Similar

found by Rehman et al. (2017) with M% less than 20%. Lalander et al. (2018) reported a range of 0 - 19%, except for wastewater. In Table 4, it was possible to identify the type of substrate used for larval production ( $F = 917.81$ ,  $P < 0.0001$ ), cooking ( $F = 270.43$ ,  $P < 0.0001$ ) and the interaction between both ( $F = 261.12$ ,  $P < 0.0001$ ) significantly influenced the %BSF mortality. The apparent digestibility analysis was carried out for the treatments with the lowest % mortality, obtaining 20.39% in T5, 12.66% in T2, 10.61% in T4, and 5.97% in T7.

In treatments T1 and T3, which had cooked and raw cattle blood respectively, as they were liquid in consistency, they were thickened by adding dry feed; the cooked blood being more digestible and assimilable by the soldier fly larvae than the raw blood. These two treatments, together with T6, presented the highest mortality % over time since they initiated a decomposition natural process which

Table 5: Comparison of meal nutritional parameters according to four viable treatments

Meal nutritional parameters	T2	T4	T5	T7
TDM (%)	26.82	91.93	93.65	97.89
H (%)	73.18	8.07	6.35	2.11
CP (%DM)	50.81	53.90	41.11	42.63
EE (%DM)	21.88	15.04	19.55	32.03
A (%DM)	5.04	5.75	8.09	6.08
CF (%DM)	5.47	4.87	5.91	5.00
NFE (%DM)	16.79	20.44	25.34	14.27
VOM (%DM)	94.96	93.92	91.91	93.92

makes the humidity and temperature not ideal for larval survival, as indicated by Tomberlin (Tomberlin and Sheppard, 2002), while T3, being cooked, its decomposition is slower, here, dry and hard complexes are formed. These three substrates have the lowest growth and weight, and the highest mortality, confirming that blood is not a viable substrate for BSF larval development. In raw chicken viscera substrate, the pH is acidified, which is not suitable for larval development, several studies indicate that a pH above 6 to 10 is more appropriate (Meneguz et al., 2018), since BSF is capable of regulating the pH of liquid alkaline substrate but not strongly acidic medium (Singh and Kumari, 2019). Factors like organic matter, protein, non-fibrous carbohydrates (NFC), and lipids are important to determine quality nutrition (Barragán-Fonseca et al., 2018, Gold et al., 2018, Gold et al., 2020, Tinder et al., 2017); thus viscera wastes are rich in organic matter, protein (50–63%) and lipids (Kazemi-Bonchenari et al., 2017), it had almost no NFC (Gold et al., 2020), with controlled density (humidity), proportion-based in balanced feed, instead, blood wastes do not have necessary nutritional requirements (liquid consistency, low protein, and fat). Considering the previous results, treatments T2, T4, and T7 were selected as the most viable, discarding T1, T3, and T6 due to their mortality percent higher than 50%. Table 5 shows the comparison of the 3 meals and the control, where T4 has the highest level of crude protein of 53.90 % and low fat of 15.04%, the T2 treatment with 50.81% crude protein and fat of 21.88 %, both T2 and T4 have a notably higher percentage than the control treatment T5 of 41.11% protein, which indicates that the residual substrates have been assimilated.

The T4 treatment of cooked beef viscera was the substrate with maximum protein amount obtained,

but not the most viable due to the weight, size, and mortality of larvae. Being T2 treatment of raw beef viscera was the optimum for obtaining high protein content *Hermetia Illucens* meal, with a crude protein value of 50.81 %, being above the range reported by other authors that goes from 42.00% to 45.00% CP (Hopkins et al., 2021); exceeding by more than 10.00% the content of soybeans, 41.10%, Beetles, 42.20%, *Eristalis tenax*, 40.90%, *Tenebrio molitor*, 38.30% to Crickets, 32.60%, fruits and vegetables, 12.90% to 18.40% (Adámková et al., 2017; Barbi et al., 2020; Cashion et al., 2017; Hu et al., 2020; Kuntadi et al., 2018; Nesic and Zagon, 2019; Nyakeri et al., 2017; Sogari et al., 2019; Zielińska et al., 2015). Compared to other organic wastes, such as fruit and vegetable wastes, 48.00%, distillers' grains and cellulose wastes, 47.00 %, being lower values; wheat and barley grain wastes, 41.00 % to 54.00 % (Barragán-Fonseca et al., 2018; Bava et al., 2019; Chia et al., 2020; Salomone et al., 2017), with values like the one obtained. The highest protein content was found in BSF fed with *S. aurita* fish waste, 77.40% a 78.80 % (Barroso et al., 2019). Likewise, the ethereal extract of T2, with 21.88%, is within the range reported between 18.10% and 35.00% (Nyakeri et al., 2017; Weththasinghe et al., 2021), this parameter varies depending on the substrate on which the crop is grown (Nyakeri et al., 2017). Soldier fly meal exhibits a good amino acid and fatty acid profile suitable for inclusion in feed, with high levels of monounsaturated and polyunsaturated fatty acids such as lauric acid (59%), linoleic acid (98%),  $\alpha$ -linolenic acid (0.79%) (Renna et al., 2017), palmitic acid (15,23 %) and myristic acid (14,34%) (Abduh et al., 2022). In recent years, insect species have received increasing attention as ingredients for animal feed production (Makkar et al., 2014; Nesic

and Zagon, 2019); such as *Tenebrio molitor*, which is being studied in the feeding of *Hypulus* rabbits, proving its additional efficiency in digestibility and nitrogen parameters (Kowalska *et al.*, 2021); and *Hermetia illucens*, in guinea pig feed at 16.00% improving feed conversion to  $2.50 \pm 0.04$  and with no detrimental effects (Reátegui *et al.*, 2020), and in aquaculture feeds, using zebrafish as an animal model, replacing 100.00% of its protein source and tripling its body weight (Fronte *et al.*, 2021), replacing fish meal in *Totoaba macdonaldi* (Villanueva-Gutiérrez *et al.*, 2022), also several studies that support BSFL meal can improve the disease resistance of aquatic animals against pathogens (Mohan *et al.*, 2022). Although the mass production of insects is still under review (Sogari *et al.*, 2019), the production of BSF larval meal is increasing, due to its high protein content, its form of consumption and sustainability must be optimized (Addeo *et al.*, 2021; Weththasinghe *et al.*, 2021). Hence, waste management with insect larvae is considered one of the most efficient techniques for resource recovery.

## CONCLUSIONS

The increase in the human population has generated a massive demand for animal protein and has created the need to seek protein alternatives in a climate emergency context. Currently, insects are cultivated to produce protein-rich foods and replace more polluting productions. *Hermetia illucens* is a saprophytic species, which colonizes and bioprocesses poultry and cattle slaughterhouse waste to convert it into its body mass; raw beef viscera was the most viable substrate generating more crude protein (50,81% - 53,90%) than the standard balanced feed (41,11%), being a valuable experimental data to scale and use this residual to finally obtain high protein meal as food substrate. The treatments with BSF meal represent a valid alternative; due to its low carbon footprint in production and its high nutritional value, it is a promising sustainable innovation, which can be applied as a supplement or added to animal feed. BSF meal is being recognized as a feed ingredient in animals for its protein-rich content. An additional factor is that this process represents a complete management of residues; frass can be recovered and used as fertilizers for its multiple plant nutrients, larval fats can be extracted to obtain

biodiesel, and chitin from adulthood. The BSF rearing system can be implemented at all levels of society and technology, this approach, which also incorporates cost considerations, is applied for feed formulation in commercial livestock production. Future research should investigate whether these results are transferable to treatment plants with higher larval densities and feeding temperatures. Various balanced formulations of biowaste should be investigated with additional analytical resources and new technologies.

## AUTHORS' CONTRIBUTIONS

A. Luperdi Puente de la Vega conceived the study and processed data, S. Flores Calla analyzed data and wrote the manuscript, X. Barriga processed and analyzed data, V. Rivera Valdez wrote and translated the manuscript, P. Manrique conducted experiments and statistical analyses, I. Salazar Churata conducted experiments, J. Reátegui Ordoñez conducted experiments. All authors read and approved the final manuscript.

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## CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

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## ABBREVIATIONS

°C	Degrees Celsius
° ' "	Degrees, latitude, altitude
%	Percent
%DM	Percentage of dry matter
%M	Percentage of mortality
A	Ash
AD	Apparent digestibility
AOAC	Association of official analytical chemists
ANOVA	Analysis of variance
BID	Banco Interamericano de Desarrollo
BM	Banco mundial
BOD	Biochemical oxygen demand
BSF	Black soldier fly
CF	Crude fiber
CP	Crude protein
EE	Ethereal extract
F	Statistical value F
g	Gram
GHG	Greenhouse gases
GI	???
h	Hours
H	Humidity

<i>INIA</i>	Instituto Nacional de Innovación Agraria
<i>kg</i>	Kilograms
<i>MPL</i>	Maximum permissible limit
<i>m.a.s.l.</i>	Meters above sea level
<i>mg/L</i>	Milligram per liter
<i>mm</i>	Milimeters
<i>M</i>	Moisture
<i>NFE</i>	Nitrogen free extract
<i>NFC</i>	Non-fibrous carbohydrates
<i>P</i>	Probability value
<i>PNIA</i>	Programa Nacional de Innovación Agropecuaria
<i>T1</i>	Treatment 1, raw beef blood
<i>T2</i>	Treatment 2, raw beef viscera
<i>T3</i>	Treatment 3, cooked beef blood
<i>T4</i>	Treatment 4, cooked beef viscera
<i>T5</i>	Treatment 5, standard balanced feed
<i>T6</i>	Treatment 6, raw chicken viscera
<i>T7</i>	Treatment 7, cooked chicken viscera

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ORIGINAL RESEARCH PAPER

# Risk assessment of fine particulate matter exposure attributed to the presence of the cement industry

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## ABSTRACT

**BACKGROUND AND OBJECTIVES:** Chronic exposure to fine particulate matter may cause adverse health impacts on humans. The impact of fine particulate matter collected in the industrial area was explored. Therefore, this study aimed 1) to assess the levels and spatial distribution of fine particulate matter and 2) to estimate the health risks due to the exposure of fine particulate matter in the population surrounding the Maros cement industry. A Monte Carlo Simulation model with 10.000 iterations was used for risk analysis through the inhalation pathway.

**FINDINGS:** The average fine particulate matter concentration was 23.68 micrograms per cubic meter, above the air quality guidelines of the World Health Organization. However, the Monte Carlo Simulation to assess the health risk with the 95<sup>th</sup> percentile demonstrated that children and adults are at low risk for developing adverse health effects. The result of sensitivity analysis showed that duration of exposure (27.0%) and concentration of fine particulate matter (25.7%) were the most contributing factors to health risks in adults and children, respectively. This new approach determines the critical factors with major effects on reducing the health risk of the vulnerable population

**CONCLUSION:** Fine particulate matter poses health risks to adults and children, despite the calculated risks are still acceptable. Thus, limiting exposure duration and maintaining fine particulate matter levels in the residential area are needed.

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## INTRODUCTION

In recent decades, air pollution cases have been broadly recognized as a potential hazard to public health and a threat to economic growth. Approximately, there are 4.2 million deaths annually caused by ambient air pollution (Shaddick *et al.*, 2020). Based on World Health Organization (WHO) data, one out of every nine deaths in 2012 was related this pollution (WHO, 2016). The cement industry is one of the largest contributors to air particulate and 5% of global CO<sub>2</sub> emissions (Abu-Allaban and Abu-Qudais, 2011). There are various pollutants from cement plants, such as sulfur dioxide, radioactive dust, hydrogen chloride, hydrogen fluoride, organic compounds, dioxins, furans, nitrogen oxide, hydrocarbon, heavy metals, and carbon monoxide, which are related to health problems and environmental impacts (Astuti *et al.*, 2021c; Emetere and Dania, 2019; Mallongi *et al.*, 2019; Ogunkunle and Fatoba, 2014; Rauf *et al.*, 2021a, 2021b). Primarily, the air pollutants in cement factories come from the clinker (Schuhmacher *et al.*, 2004). Dust is released from quarrying, stockpiles, raw material transportation, clinker cooler, crusher, grinders, materials-handling equipment, kilns operation, and milling proces (Abu-Allaban and Abu-Qudais, 2011; Mishra and Siddiqui, 2014). It may easily be transported by wind to different places from point sources. Greenhous gases (GHG) such as nitrogen, carbon, and sulfur oxides are mainly produced by fossil fuel combustion for power generation, kiln, and drying. SO<sub>2</sub> is emitted from the oxidation process of limestone as the cement raw material (Abu-Allaban and Abu-Qudais, 2011). The cement factory is one of the main sources of particulates based on many studies (Fell and Nordby, 2017; Kholodov *et al.*, 2020; Mallongi *et al.*, 2021; Mehraj *et al.*, 2013; Mishra and Siddiqui, 2014; Nkhama *et al.*, 2017; Rauf *et al.*, 2021b, 2022). Particulate matter (PM) consists of fine and coarse particles (Mekasha *et al.*, 2018) sourced from cement mills, packaging, fuel combustion and preparation, stacks, and road cleaning in the form of carbon and dust (Mishra and Siddiqui, 2014). Particulate matter is also produced when raw material processing (quarrying, crushing, hauling, grinding of limestone and clay) and clinker. Particles suspended in ambient air have various sizes, grouped to TSP (Total Suspended Particle) up to 100 microns in size, PM<sub>10</sub> (particles with a size of < 10 microns) and PM<sub>2.5</sub>

(particles with a size of < 2.5 microns). PM<sub>10</sub> and PM<sub>2.5</sub> can enter and cause irritation and damage to the respiratory system. Particulate matter (PM) can contain potentially toxic heavy metals such as Pb, Cd, Cr, As, Ni, Mn, Zn, Mo, Cu, and Ba posing adverse health problems (Ahmad *et al.*, 2013). In addition, PM<sub>2.5</sub> can absorb organic compounds such as nitro-PAH and PAHs, ammonium, nitrate, sulfate, organic carbon, and element carbon from vehicles (Motesaddi Zarandi, 2019). The low concentration of PM<sub>2.5</sub> is still dangerous to human humans due to its adverse health effects. This emission is toxic because it contains mutagens, immunotoxins, respiratory toxins, neurological toxins, and carcinogenic agents. PM<sub>2.5</sub> can freely enter the respiratory tract and get deposited in the lungs' alveoli before entering the bloodstream. The dust may enter the human body through the gastrointestinal tract through contaminated foods (Mishra and Siddiqui, 2014). PM<sub>2.5</sub> is more dangerous to human health than PM<sub>10</sub> (Ahmad *et al.*, 2013). Short-term exposure to PM<sub>2.5</sub> may increase the risk of respiratory and cardiovascular disease. PM<sub>2.5</sub> is positively related to coronary heart disease mortality (Ahmad *et al.*, 2013). Around 3% and 5% deaths cases are associated with cardiopulmonary disease and lung cancer, respectively which are from PM<sub>2.5</sub> exposure (Mekasha *et al.*, 2018). Several studies showed that the exposure may significantly reduce lung functions and cancer in cement workers and the community surrounding the plant (Fell and Nordby, 2017; Kholodov *et al.*, 2020; Nkhama *et al.*, 2017). The recent study by Nkhama *et al.* (2017) showed that people exposed to PM<sub>2.5</sub> had lower lung capacity. Other study by Novirsa and Achmadhi, (2012) showed that several points exceed the US-EPA quality standard of 0.03 mg/m<sup>3</sup> based on the findings of ambient air study near the cement industrial area of Padang City. Sampling point at ring 2, 4 and 5 with a distance of 500 - 1000 m, 1,500–2,000 m, and 2,000 – 2,500 m from the center of the factory has PM<sub>2.5</sub> concentration of 0.041 mg/m<sup>3</sup>, 0.038 mg/m<sup>3</sup> and 0.037 mg/m<sup>3</sup> (Novirsa and Achmadi, 2012). In the study by Kholodov *et al.* (2020) adverse health impacts due to cement dust and its related substances exposure are skin irritation and allergic dermatitis, respiratory track (asthma, silicosis, and chronic bronchitis), nasopharyngeal mucosa, and the oral cavity, and digestive tract disorders. Various materials contained

in  $PM_{2.5}$  can cause various respiratory disorders such as infections acute respiratory infection (ARI), lung cancer, cardiovascular disease, premature death, chronic obstructive pulmonary disease (COPD). [Correia et al. \(2013\)](#) showed that a decrease in  $PM_{2.5}$  concentrations was associated with an increase in life expectancy of 0.35 years. Another study by [Sánchez-Soberón, \(2017\)](#) stated that heavy metals concentration such as Cr(VI) may cause cancer among cement workers which are exposed from indoor activities (working /leisure and sleeping). WHO recommends a safe level of  $PM_{2.5}$  exposure of  $25 \mu g/m^3$  in a 24-h period (not exceeding 3 days a year) and  $10 \mu g/m^3$  annually ([Nkhama et al., 2017](#)). Meanwhile, the United States Environmental Protection Agency (USEPA) recommends  $35 \mu g/m^3$  in 24-h exposure to  $PM_{2.5}$  ([Nkhama et al., 2017](#)). Maros Regency has a potential limestone mining area surrounding the karst area. The cement industry is one of the largest companies in Maros regency, producing 1.8 million/tons of cement annually. The plant is near a residential area (< 50 m), which may expose the people surrounding it to health hazards ([Rauf et al., 2021a](#)). According to [Rauf et al. \(2021b\)](#), TSP emitted by the Maros Cement Plant exceeded the minimum safe level by ambient air quality. As a result, the people living near the plant are at risk of non-carcinogenic cases ( $HQ > 1$ ). This may be caused by heavy metals bound in particulate. Based on annual health data in Maros Regency, cough, dermatitis, influenza, and acute respiratory infection are the major morbidity cases in Maros regency ([Dinkes Maros, 2015](#)). Morbidity cases are suspected due to exposure to  $PM_{2.5}$  and dust in the air produced by the cement industry in Maros Regency. Therefore, a study related to  $PM_{2.5}$  exposure and health risk assessment is needed in this area to predict health risks due to air pollution from the cement factory. A recent study also showed that exposure to heavy metals, which are bounded to dust through inhalation, oral and dermal, may cause non-carcinogenic ( $HQ > 1$ ) and carcinogenic cases ( $TCR > 10^{-6}$ ) ([Rauf et al., 2021b](#)). Several studies showed that the presence of the cement industry surrounding the karst area is attributed to an increase in ecological and human health risks ([Astuti et al., 2022; Mallongi et al., 2022; Rauf et al., 2021b](#)) due to the accumulation of heavy metals in the environment. Study associated with  $PM_{2.5}$  pollution and its contribution to human health

in South Sulawesi Province is limited. Previous study in Maros regency showed a health risk due to exposure to TSP (Total Suspended Particle) from the cement industry in Maros ([Rauf, 2021a](#)). Furthermore, the Monte Carlo Simulation (MCS) model is still limited to identify health risks due to hazardous substances from ambient air. The model has just been carried out to identify uncertainty in the point estimate of exposure from the conservative human health risk assessment method by USEPA and sensitivity of exposure parameters analysis. Most of the MCS method was used in several studies on the chemical exposure from the soil, water, and food ([Astuti, et al., 2022; Jimenez-Oyola et al., 2021; Rajasekhar et al., 2018](#)). Few studies used MCS to rank exposure pathways, locations, and contaminants from air pollution, particularly  $PM_{2.5}$  exposure. Previously, the MCS model estimated health risks from air pollutants such as heavy metals ([Chen et al., 2022; Chen et al., 2022; Dehghani et al., 2021; Rauf et al., 2021b; Wang et al., 2019](#)); sulphate, nitrate, ammonium, organic carbon (OC)-bounded to  $PM_{2.5}$  ([Wu et al., 2021](#)); polycyclic aromatic hydrocarbon ([Mo et al., 2019; Motesaddi Zarandi et al., 2019](#));  $O_3$  ([de Souza Silva et al., 2016](#)). High uncertainty may appear in the risk assessment process when using deterministic parameters. The probabilistic assessment method such as Monte Carlo Simulation can diminish risk assessment uncertainties by analyzing the concentration of pollutants and other toxicity factors ([USEPA, 1997](#)). [Jimenez-Oyola et al., \(2021\)](#) mentioned that human health risk assessment problems lack information about exposure in the population and often use default values from the literature that cannot describe the real condition, leading to under or overestimation of health risks. Probability risk assessment using the MCS method can overcome these constraints. This method is useful for risk assessors making future management actions ([USEPA, 1997](#)). Therefore, the MCS method is used to assess health risks from  $PM_{2.5}$  exposure to people surrounding the cement industry of Maros Regency. This is the first study that used this method to assess  $PM_{2.5}$  exposure in an industrial area. The study purposes are 1) identification of  $PM_{2.5}$  concentration in ambient air environment surrounding area near the largest cement industry in Maros Regency, and 2) estimation of health risk due to  $PM_{2.5}$  exposure using Monte Carlo Simulation

method. This study may be useful to make environmental risk management in the future. It was carried out in Maros Regency, South Sulawesi Province, Indonesia, in 2022.

## MATERIALS AND METHODS

### Sampling process

The  $PM_{2.5}$  level was measured for 10 days in March 2022. The total concentrations in the outdoor environments were measured in four major sub-districts of Salenrang, Baruga, Bungaeja, and Tukamasea. The meteorological data (i.e., temperature, relative humidity, and wind speed) and the daily concentration during the sampling period were applied. In this study, 5 selected residences were selected as they were the nearest location to industrial activities. In 2020, total resident in the sampling sites was 30,488 (BPSSMR, 2020). Sites 1, 2, 5, 11, 16 and 18 are within the Lau area, around 2.1 km from the cement factory and 700 m – 2.5

km from traditional rock mining. This area is in the west and southwest regions, where the air quality is influenced by heavy-duty trucks' transportation of raw materials and industrial products distribution as well as vehicles fume from the main road. Sites 6, 7, 12, and 17 are the distinct village areas occupied by residents before the industrial activities began. This area is located in the southwest, Mattoangin region, about 2 - 3.5 km from the main industrial activities in the north. There is always yellow and white dust on residents' terraces, even when the wind does not blow predominantly in this direction, specifically in the morning. Sites 3, 8, 9, 13, 18, and 19 are located in the Baruga area, where the cement factory is in the south, approximately 500 m - 3.4 km from a cement plant and 3.77 km from a marble factory in the southeast. This area was one of the most densely populated residences working as farmers. Sites 4, 10, 14, 15, 20, and 21 are located in Tukamasea and Leang-Leang areas which residents in the east

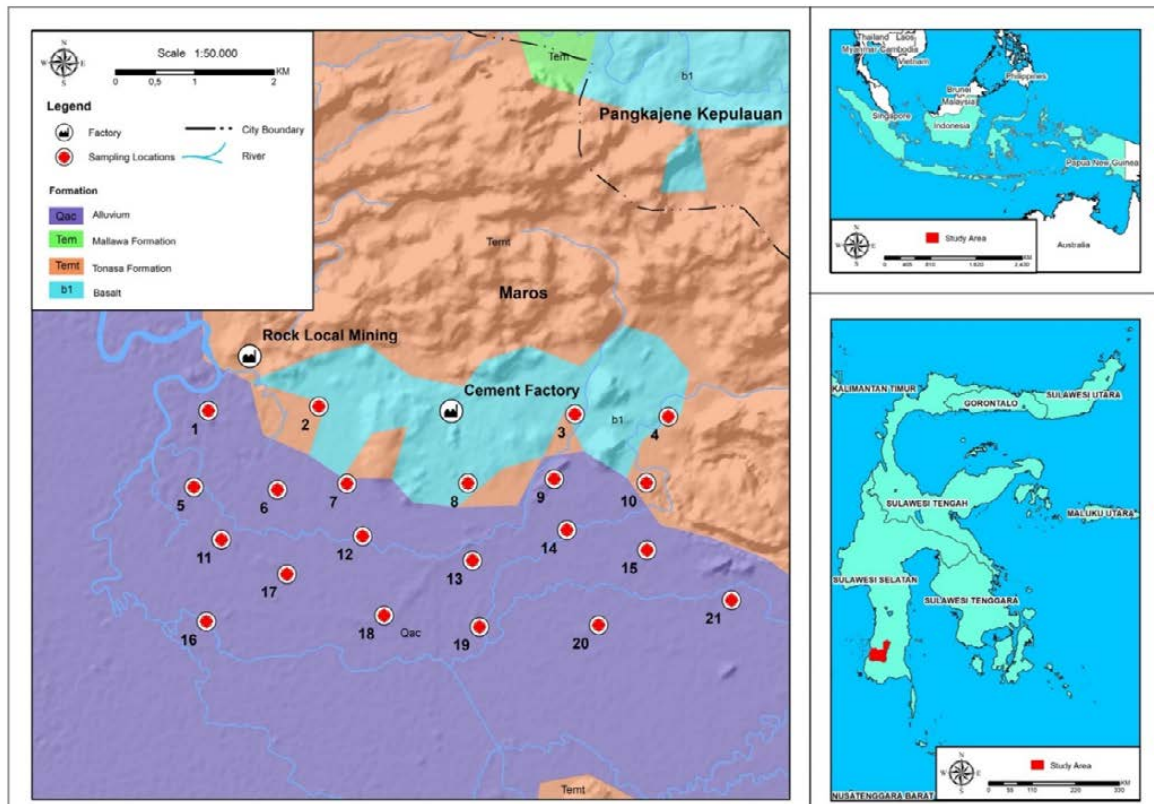


Fig. 1: Geographic location of the study area along with the sampling locations of  $PM_{2.5}$  in the in four major sub-districts in Indonesia

and southeast inhabit. In this area, traffic volume was relatively low. The residents mostly worked as blue-collar workers and farmers. No sampling was carried out in the north, northeast, or northwest of the factories, as these areas were uninhabited and surrounded by karst hill (Tonasa limestone Formation). Measurement of  $PM_{2.5}$  concentration was carried out at 21 stations, namely 2 points at the front gate, the next 6 points each 100 m from the main gate, then 3 points at the entrance to the residential area, and 10 points inside the settlement (Fig. 1).  $PM_{2.5}$  sampling was carried out using direct reading HAZ-Dust EPAM 5000. That equipment uses a laser analyzer to measure particulate. The measurement result or time-weighted average (TWA) value can be directly read after the measurement process is conducted. The meteorological data was collected from Indonesia Agency for Meteorology, Climatology, and Geophysics online database. Fig. 2 showed the wind directions or model dispersion of  $PM_{2.5}$  in the cement industry of Maros during the sampling process. That model was carried out using wind rose plot software (WRPLOT 4.0.1 for  $PM_{2.5}$  concentration).

#### Data analysis

Human health risk analysis by USEPA was used to estimate health risk of  $PM_{2.5}$  exposure in people surrounding cement factory. Inhalation is the main route for  $PM_{2.5}$ , thus health risk analysis was focus to this route. The equation for inhalation route non-carcinogenic risk analysis is shown in Eqs. 1 and 2 (Edlund et al., 2021; Rauf et al., 2021a, 2021b; USEPA, 2001, 1989).

$$ADD_{inh} = \frac{C \times Inh_{rate} \times EF \times ED \times ET}{BW \times AT} \quad (1)$$

$$HQ = \frac{ADD_{inh}}{RfC} \quad (2)$$

Where, ADD is the average daily doses of  $PM_{2.5}$  ( $\mu g/kg/day$ ), C is ambient  $PM_{2.5}$  concentration ( $\mu g/m^3$ );  $Inh_{rate}$  is inhalation rate of people, USEPA default value  $14.9 m^3/day$  (adult) and  $9 m^3/day$  (children) (USEPA, 1989), EF is  $PM_{2.5}$  exposure frequency 350 days/year for residential exposure (USEPA, 1991), ED is exposure duration, USEPA default value for adult 24 years and 6 years (Rauf et al., 2021b), BW is body

weight for adult 63.01 kg (adult) and 34.55 (children) (Rauf et al., 2021b), AT is averaging time ( $ED \times 365$  days/years for non-carcinogenic risk estimation), RfC is reference concentration for  $PM_{2.5}$  inhalation is  $10 \mu g/kg/day$  (Novirsa and Achmadi, 2012). If HQ value exceeds 1, it indicated that the chronic  $PM_{2.5}$  exposure is not safe for the population. It is potentially cause non-carcinogenic health impacts in the future. Otherwise, when the HQ value is lower than 1, there is no non-carcinogenic risk to population or the risk is negligible. Monte Carlo Simulation (MCS) model was used in this study to estimate uncertainty or distribution of probability risk and contribution of variable to non-carcinogenic risk in the Maros cement industry population. The MCS model has been used in many risk estimation study (Astuti et al., 2022; Gao et al., 2019; Mallongi et al., 2022; Pelletier et al., 2017; Rauf et al., 2021b; Saha et al., 2016; Tajdar-oranj et al., 2018) and is recommended by USEPA, (1997) for health risk estimation process. Based on the previous study, default value such as inhalation rate and other variables to estimate health risk is potentially rise the ambiguity and uncertainty of risk (Rauf et al., 2021b). Thus, using MCS to estimate the distribution of probability risk is need to be done. The MCS was performed with 10000 repetitions to examine uncertainties related to non-carcinogenic risk. In this study, the variables that were analyzed for sensitivity test using MCS are ED, EF, C, and BW. This model investigating the distribution of random variables by simulating random numbers (Millard, 1998). Usually the random number expressed as Y, variables in health risk assessment. In this case, the random vector X may represent observations from several kinds of distributions that characterize exposure and dose response. The distribution of the main variables was used to find the correlation between  $PM_{2.5}$  exposure and the probability of health risk in human. The function of the selected variables in the Monte Carlo simulation is expressed in Eq. 3.

$$Y = h(X) = h(X_1, X_2, \dots, X_n) \quad (3)$$

The result was presented in graphic of probability risk (uncertainty) and sensitivity of variables. The MCS was carried out using the Oracle Crystall Ball software (11.1.12 ver) in Microsoft excel 2019 add-in. In this study, the mean concentration of  $PM_{2.5}$  and risk calculation were performed using Microsoft

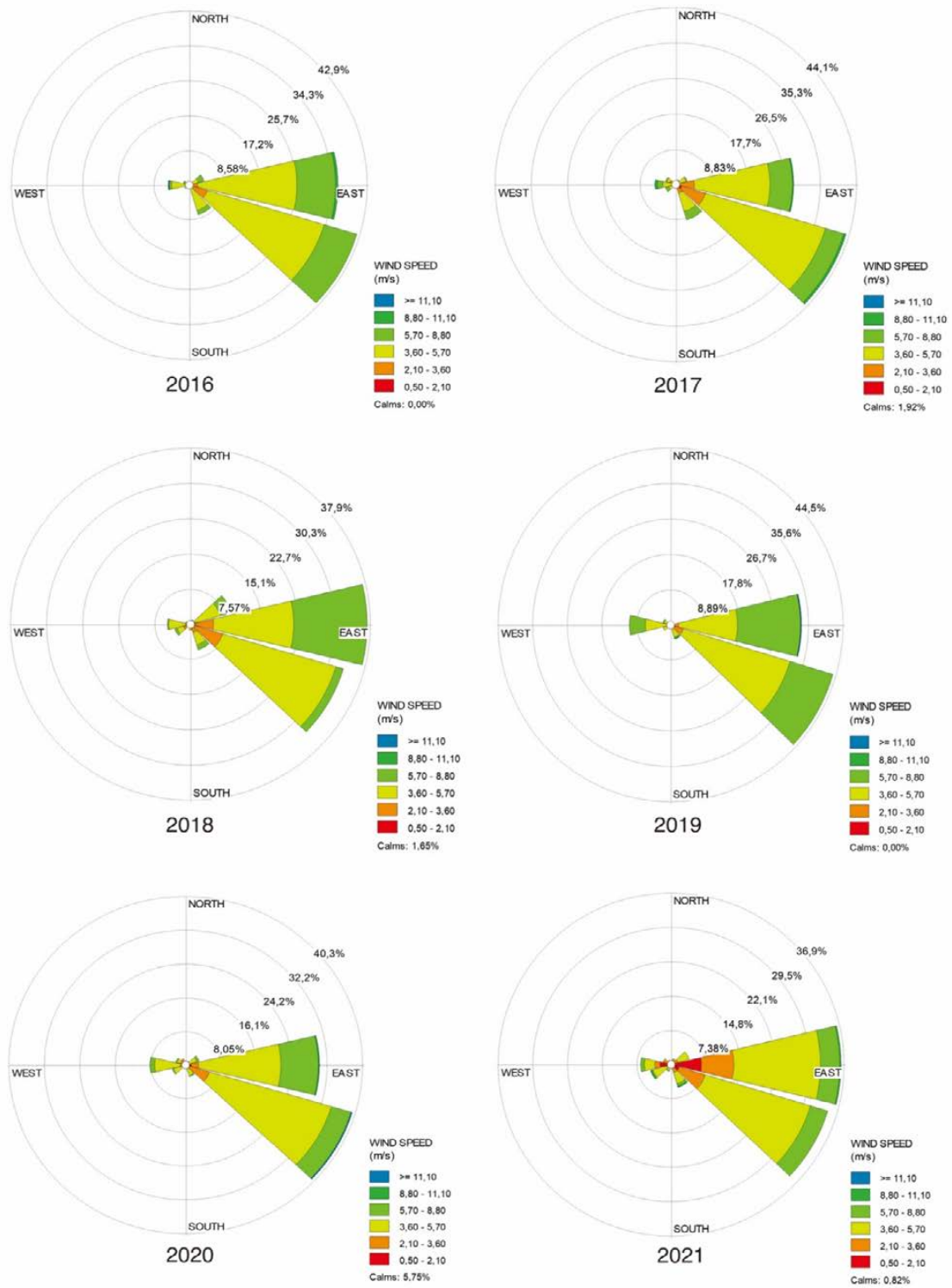


Fig. 2: Annual wind condition around the cement plant complex in 2016 – 2021

Excel version 2019. Spatial distribution of  $PM_{2.5}$  concentrations was carried out by ArcGIS.

## RESULTS AND DISCUSSION

### Meteorological data

Meteorology is an important factor in the distribution and accumulation of particulates. It is the main component in determining the dilution effect of the atmosphere because the released substances are carried by the wind (Goudarzi *et al.*, 2018; Kim *et al.*, 2015). Temperature, wind speed, direction, and humidity were compiled from the Indonesian Meteorological, Climatological and Geophysical Agency (BMKG) online database. During the sampling days, temperatures ranged between 25.6 and 31.08°C, with an average value of 29.02°C, relative humidity ranged between 71.11% and 87%, average 81.6%, and wind speed ranged between 1.8 and 4.0 m/s, average 2.8 m/s. Fig. 2 indicates that the wind was heading Southeast and East. These

locations are the main residential area in Tukamasea and Bungaeja Villages, with a resultant vector of this visualization at 109°. For six years, wind patterns were fairly consistent despite daily changes in direction (2016– 2021). The windrose plot was processed with Microsoft Excel software and WRPLOT 4.0.1 from Lakes Environmental Software. It was confirmed that the particulate concentration near cement plant areas in Southeast and East was higher than in others. Therefore, the residents will continuously be exposed to more particulates due to the wind direction.

### $PM_{2.5}$ mass concentration

Direct measurements were carried out from morning to evening. The results showed that the concentration of PM varied at each point. The spatial distributions are presented in Fig. 3, while the differences in  $PM_{2.5}$  concentration in Maros Regency and other countries are depicted in Table 1. The average concentration of 23.68  $\mu g/m^3$  was

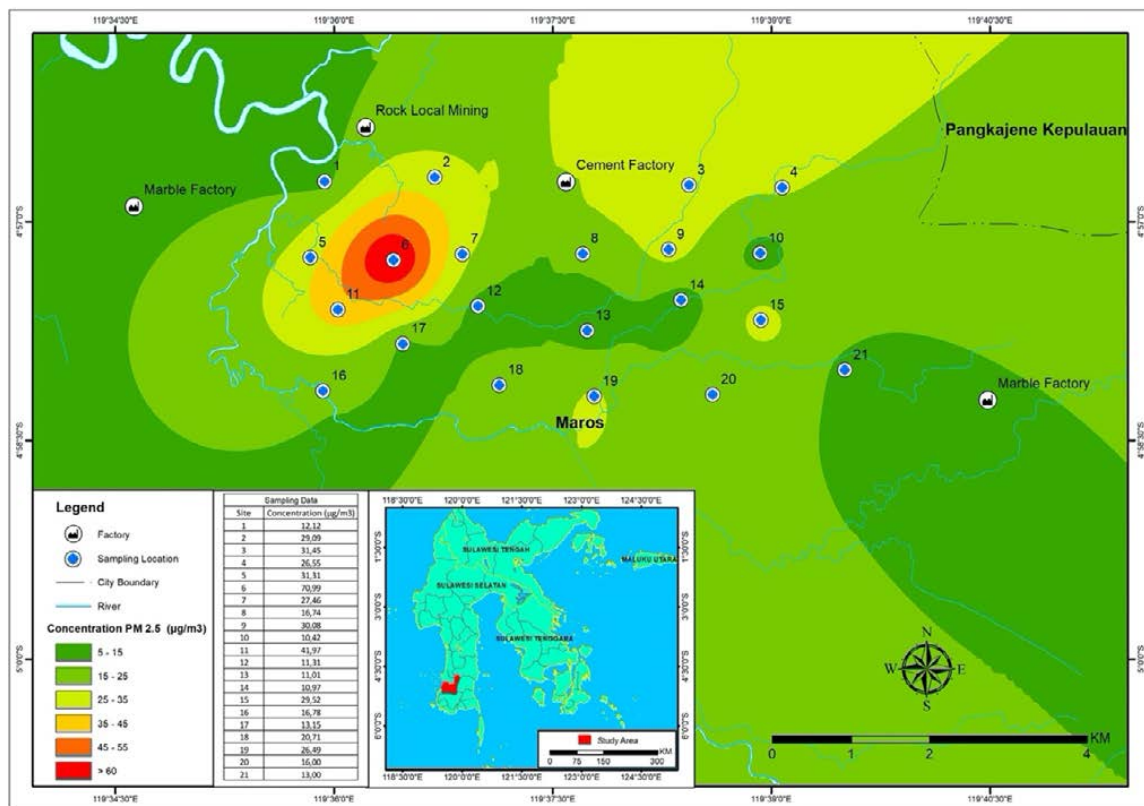


Fig. 3: The spatial distribution of  $PM_{2.5}$  levels around the residential areas

found for this study, which was higher than WHO Air Quality Guideline (AQG). WHO-AQGs of PM<sub>2.5</sub> for short-term (24-h average) and long-term (annual average) exposures are 15 µg/m<sup>3</sup> and 5 µg/m<sup>3</sup> (WHO, 2021). Alternatively, this concentration is still below the Indonesian standard for air quality (Indonesian government, 2021). The highest concentration of PM<sub>2.5</sub> found in station 6 (70.99 µg/m<sup>3</sup>) is located in the south-eastern part of the cement plant, precisely in Tukamasea Village. This area is flat, quite lower, placed on alluvial plain and inhabited by most residents who work as farmers. The distribution of particulates originating from industrial activities from the direction of the Karst mountains in the north may increase PM<sub>2.5</sub> concentrations. The result was under a previous study, where the highest total suspended particulate (TSP) bound to metals was recorded at this location (Rauf et al., 2021a; Rauf et al., 2021b). According to the literature, PM<sub>2.5</sub> pollution might be affected by meteorological conditions, anthropogenic activities, and soil resuspension (Nkhama et al., 2017; Peng et al., 2016; Shahri et al., 2019).

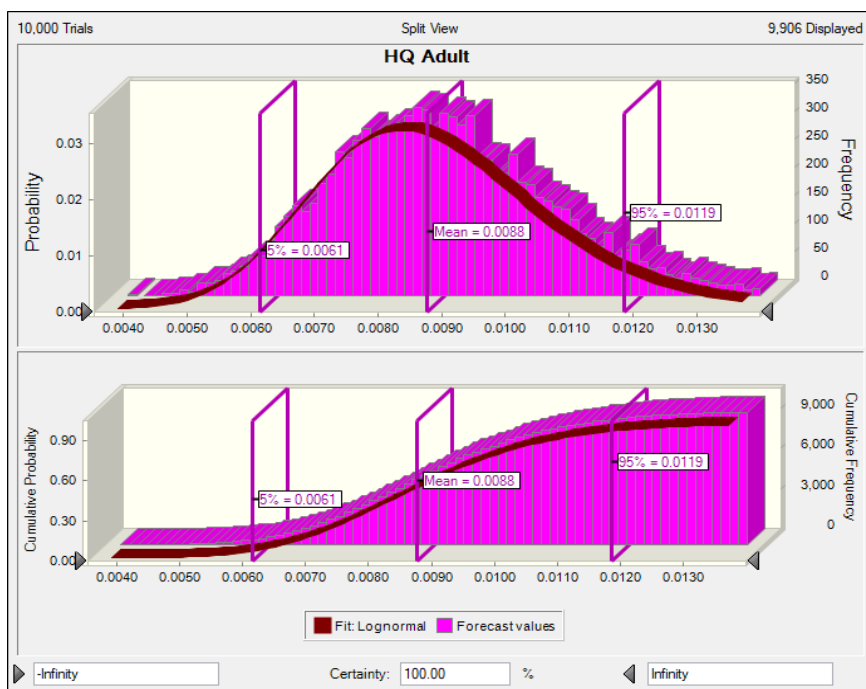
Maros karst area is surrounded by karst quarries, cement, and marble factories operating for the last two decades. The majority of industry in this region involves dry processes and high temperatures in their production activity. In cement factories, the particulates generated from the stacks may carry toxic particulates such as PAHs, heavy metals, and organic matters that are harmful to the surrounding population (Astuti et al., 2021b; Mallongi et al., 2022;

Naeini et al., 2019; Rauf et al., 2021b). In addition, the use of coal in industry releases heavy metal ions involving high temperatures, which are likely to increase the risk to human health (Kim et al., 2015). This indicates the higher the mass of particulates produced from industrial chimneys, the possibility of a high accumulation of toxic elements in other media such as soil and water bodies will increase (Han et al., 2015; Kurt, 2018; Rauf et al., 2022). Based on Table 1, the concentration of PM<sub>2.5</sub> around cement plants mostly exceeds WHO's standard (WHO, 2021).

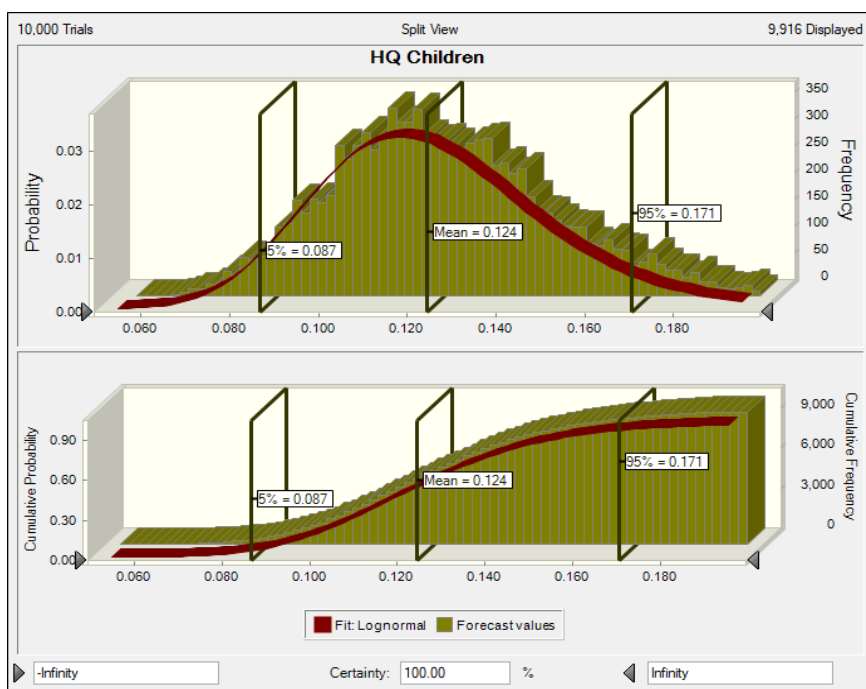
Natural enrichments around karst areas are likely to occur where the wind will consistently blow and move the dust to residential areas (Ayanlade and Oyegbade, 2016; Han et al., 2021; Rauf et al., 2020b). Anthropogenic origin (mostly attributed to secondary particle formation) and natural sources (dust) contribute 17% and 16% to ambient PM in European and Central Asia urban areas (Almeida et al., 2020). In Indonesia, limestone and marble are the main minerals of cement production. The conversion into cement by heat releases carbon dioxide and metals as a waste product (Rauf et al., 2020a). In a study conducted in the Districts of Chelyabinsk, Russia, PM<sub>2.5</sub> concentrations were higher around industrial areas at 303 ng/m<sup>3</sup> than in non-industrialized areas at 192 ng/m<sup>3</sup>. This is because the area has more intense activities and uses coal-fired stations (Krupnova et al., 2021). In non-industrial areas, the accumulation of PM<sub>2.5</sub> is mostly caused by vehicle fumes and burning waste. According to the United

Table 1: The comparison between average concentration of PM<sub>2.5</sub> from Maros cement, other studies and air quality standards.

Region/ country	Concentration (µg/m <sup>3</sup> )	References
Maros, Indonesia	23.68	Present study
Chilanga, Zambia	10.21	(Nkhama et al., 2017)
Thohoyandou, South Africa	11.00	(Edlund et al., 2021)
Barcelona, Spain	15.20	(Sánchez-Soberón et al., 2015)
Riyadh, Saudi Arabia	21.00	(Al-Zboon et al., 2021).
Ewekoro, Nigeria	112.14	(Saheed Bada et al., 2013)
Khash, Iran	14.34	(Shahri et al., 2019)
Penglai, China	58.00	(Xue et al., 2022)
Chuncheon and Yeongwol, South Korea	23.00 and 19.70	(Han et al., 2015)
Antofagasta, Chile	42.00	(Jorquera and Barraza, 2013)
Kongo Central Province, Democratic Republic of the Congo (DRC)	48.80	(Mbelambela et al., 2020)
WHO-AQG	5 (annual) 15 (24-h)	(WHO, 2021)
Indonesian Standard for air pollution	15 (annual) 55 (24-h)	(Indonesian government, 2021)



(a)



(b)

Fig. 4: The HQ of adult (a) and children (b) from  $PM_{2.5}$  exposure

States Geological Survey, Indonesia produced 75,200 and 74,000 cement in 2017 and 2018. This number outperformed the production in Brazil (53,000), Iran (58,000), Japan (55,300), Republic of Korea (55,000), Russia (57,300) and Turkey (72,500) (USGS, 2020). The possibility of increasing cement factory activity and production will still occur in the next few years. This is worrying because the increase and demand for production can cause air pollution when it is not balanced with environmental protection policies and efforts to protect human health.

#### Health risk

In this study,  $PM_{2.5}$  and health risk implications were assessed. The risk quotient was calculated to estimate the toxicological risk where the average dose of  $PM_{2.5}$  was released to the reference. Fig. 4 depicts a health risk analysis with 95 percentile. The result indicates that children face greater risk ( $HQ = 0.171$ ) than adults ( $HQ = 0.011$ ) in the year. This result implies that the health risk posed by exposure to ambient air  $PM_{2.5}$  around the industrial area was below the USEPA standards ( $HQ < 1$ ). However, long-term exposure can accumulate toxic substances bound to  $PM_{2.5}$ . Children's potential health risk is higher than adults due to their daily activities, inhalation rate, body

weight ratio, and immature physiological system (Al-Zboon et al., 2021; de Oliveira et al., 2012; Mallongi et al., 2020). There are likely other groups with higher vulnerability and susceptibility, such as the elderly or people with diseases, at higher risk for the relevant adverse health effects (Alsafran et al., 2021; Astuti et al., 2021a; Celo et al., 2021). This is similar to a previous study conducted in Thohoyandou, South Africa, where children and infants experienced a greater carcinogenic and non-carcinogenic risks from  $PM_{2.5}$  exposure than adults (Edlund et al., 2021). Among 185 countries, the population-weighted median decrement in life expectancy from  $PM_{2.5}$  ( $\Delta LE$ ) was 1.22 years (IQR of 0.67– 1.51 years) (Apte et al., 2018). The high HQ of adults and children is attributed to the dusty weather in Indonesia for most of the year. Furthermore, the monitoring was conducted in March, which is considered the month with the windiest days (Astuti et al., 2021a; Rauf et al., 2022). Prevailing wind greatly contributes to particulate distribution in the air. Therefore, settlements that experience innate winds will accumulate more dust, particularly when they are located near industrial activities or roads (Han et al., 2021; Kim et al., 2015). This is in accordance with previous studies where the nearest area to cement will experience a higher

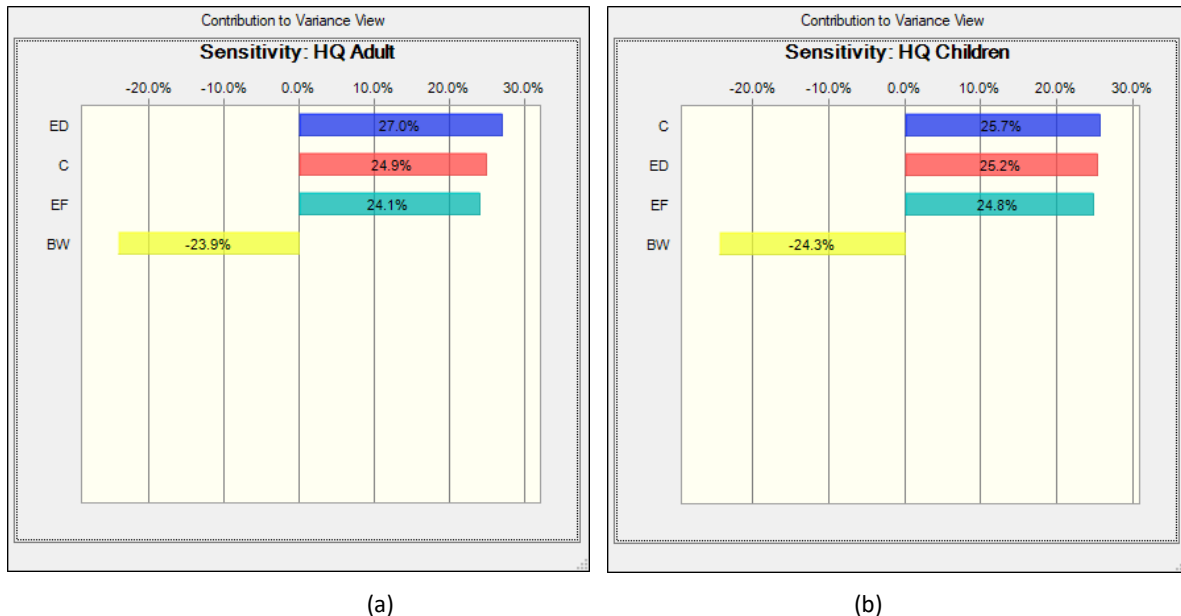


Fig. 5: The sensitivity analysis of the main variables in health risk assessment using Monte Carlo Simulation (MCS)

accumulation of dust/ash and metals in ambient air, deposited to surface soil and bodies of water. Residents who inhabit this area are threatened with respiratory diseases and skin disorders (Astuti *et al.*, 2022; García-Pérez *et al.*, 2015; Kridin *et al.*, 2016).

In Fig. 5, the sensitivity chart revealed the exposure duration (ED) was the most significant factor for increasing the health problem in adult is exposure duration (ED) (27.0%), followed by concentration (C) of  $PM_{2.5}$  (24.9%). Whereas in children, the highest contribution was the concentration (C) of  $PM_{2.5}$  (25.7%), followed by ED (25.2%). It means that the exposure to pollutants and their concentration had the highest impact on developing adverse health effects in humans. Therefore, the most suitable scenarios focus on periodic industrial emissions monitoring near residential areas and limiting exposure duration. This indicates the more often discrete exposure events occur, the higher the possibility that residents will be at risk. Hence, children and adults should reduce their activities and use protection to decrease their contact with the air pollution that possibly contains harmful materials. The contribution of body weight (BW) was negative, indicating a low effect and can be ignored.

## CONCLUSION

This study measured the outdoor level of  $PM_{2.5}$  samplings continuously over 24 hours in 21 different sites. The focus was on the residential area around the cement industry in Maros Regency. The dominant wind direction, which blows from the northeast to the southeast, causes the Tukamasea region to experience a higher accumulation of particulates from factory production. As a result, the average concentration of  $PM_{2.5}$  was higher than WHO-AQG for the short-term (24-h average) and the long-term standard (annual average). A health risk assessment was conducted through Monte Carlo Simulation (MCS) to determine the uncertainty. The proposed method identifies the potential health risks from  $PM_{2.5}$  exposure through the inhalation pathway. The 95th percentile and 10,000 trials simulation showed that adults' and children's hazard quotient (HQ) were still tolerable and within safe limits. In sensitivity analysis, exposure duration and pollutant concentration are the most influential variables in the health risks of residents in the study area. This indicates that long-

term exposure duration will still threaten human health, specifically for those close to factories. For the regulations to effectively protect the health of all age groups, the accepted levels and contact need to be reduced. This study recommends that  $PM_{2.5}$  concentration around the residential areas be maintained. Personal protective equipment such as masks is suggested. For future analysis, integrating the MCS model and health risks assessment can be considered appropriate tools for monitoring air pollution and a scientific basis to predict health risk estimation. The MCS model can assess health risks due to  $PM_{2.5}$  emissions in industrial areas and overcome the uncertainty related to health risk assessment. It may not apply to everyone, but the right scenarios and policies can go a long way toward ensuring that everyone's health is protected. Future study should focus on measuring the concentration of other pollutants bound to  $PM_{2.5}$  and its health risks.

## AUTHOR CONTRIBUTIONS

A. Mallongi performed the experimental design, prepared the manuscript text and conceptualization. S. Stang did the statistical analysis and validation. R.D.P. Astuti helped the literature review, sample collection, manuscript preparation and visualization. A.U. Rauf performed the project administration, sample collection, and data analysis. M.F. Natsir performed the sample collection and reviewing.

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## CONFLICT OF INTEREST

The author declares that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

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**ABBREVIATIONS**

$^{\circ}\text{C}$	Celcius degree
$\mu\text{g}/\text{m}^3$	Microgram per meter cubic
$\mu\text{g}/\text{kg}/\text{day}$	Microgram per kilogram per day
%	percent
24-h	24 hours
$\Delta\text{LE}$	Life Expectancy
ADD	Average daily dose
AQG	Air quality guideline
ARI	Acute respiratory infection
As	Arsenic
AT	Averaging time
Ba	Barium
BMKG	Indonesian Meteorological, Climatological, and Geophysical Agency or Badan Meteorologi, Klimatologi dan Geofisika
BW	Body weight
C	Concentration of $\text{PM}_{2.5}$

Cd	Cadmium
Cu	Copper
COPD	Chronic obstructive pulmonary disease
Cr	Chromium
Cr(VI)	Hexavalent Chromium
$\text{CO}_2$	Carbon dioxide
DRC	Democratic Republic of the Congo
ED	Exposure duration
EF	Exposure frequency
EPAM	Environmental particulate air monitoring
ET	Exposure time
GHG	Greenhouse gas
$\text{Inh}_{\text{rate}}$	Inhalation rate
IQR	Interquartile range
HQ	Hazard quotient
Mn	Manganese
m	Meter
$\text{m}^3/\text{day}$	Meter cubic per day
m/s	Meter per second
PAH	Polyaromatic hydrocarbon
Pb	Lead
PM	Particulate matter
$\text{PM}_{10}$	Particles with a size of < 10 microns
$\text{PM}_{2.5}$	Particles with a size < 2.5 microns
RfC	Reference concentration
$\text{SO}_2$	Sulphur dioxide
TCR	Total carcinogenic risk
TSP	Total Suspended Particle
TWA	Time weighted average
USEPA	United states Environmental Protection Agency
WHO	World Health Organization
WRPLOT	Wind rose plot
Zn	Zinc

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## ORIGINAL RESEARCH ARTICLE

### Production of organic fertilizer using *pleurotus* sp. as a process accelerator

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#### ABSTRACT

**BACKGROUND AND OBJECTIVES:** One of the best retributions that man can make to the environment and that promotes development is the incorporation of waste into truly productive processes. In this sense, the main objective of this study was to take advantage of the vegetal residues from tree pruning obtained from the maintenance of the overhead wiring of the electrical networks in the city of Barranquilla, in Colombia, to produce an organic fertilizer, which are some of the most demanded products in the world. The production of organic fertilizer was carried out by composting using the *Pleurotus* sp. fungus as an accelerator of the process.

**METHODS:** For compost production, three treatments were used based on a mixture of manure, pruning, banana bagasse and *Pleurotus* sp. as an accelerator process. Each treatment was layered and then arranged in beds of compost piles. The temperature and humidity were monitored throughout the process. Physicochemical parameters were measured at the end of the process in concordance with the Colombian Technical Standard 5761. To evaluate the biological efficiency of the compost, two doses were tested with each 100 gram and 200 gram of fertilizer for each 500 gram of soil using corn seeds, which were sown in bags over a period of three months. At the end of the test, biological growth parameters such as foliar development, amount of biomass and fruiting were measured.

**FINDINGS:** Most of the physicochemical and biological parameters were within the NTC 5167 standard. The treatment with the highest percentage of degradation by composting was treatment number 2 (with *Pleurotus* sp.), which showed that with 60 percent of fresh prunings in the formulation, *Pleurotus* accelerates the process by 24 percent compared to the other treatments.

**CONCLUSION:** In summary, the tested method is a good route to produce fertilizers from pruning wastes. Regarding the effect of the fertilizer on the development of corn seedlings, a positive effect was observed compared to the control. Otherwise, in the composting process, the fungus significantly accelerates the process and at the same time shows an overgrowth.

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## INTRODUCTION

Solid waste continues to be a problem worldwide and, due to the increasing amount of organics in landfills, the generation of greenhouse gases still results from a linear economy. Many studies demonstrate models in which the production of compost from different types of waste are interesting proposals for environmental sustainability, including technological adaptations and new wastes. (Rashid and Shahzad, 2021; Ajmal et al., 2021; Sun et al., 2021; Cardoso et al., 2022). In the main cities of Colombia, the circular economy has not yet been implemented. In the electricity sector the electrical networks are supported by poles, so foliage from trees often interferes with the power cables, causing failures in the electrical service and great economic losses. For this reason, the company that provides energy in a part of the Caribbean region, carries out periodic pruning, generating around 100 tons per month of plant biomass. Normally, the leaves are later collected by the local garbage collection company and taken to sanitary landfills (Aristizabal et al., 2015) where they decompose together with a large amount of solid waste, generating a negative environmental impact. A good strategy to take advantage of pruning waste and avoid the negative impact of its decomposition in sanitary landfills is the composting technique (Cestonaro et al., 2021; Mishra and Yadav, 2022). Composting is a controlled degradation process, which allows aerobic bacteria and other microorganisms to decompose organic matter (e. g. leaves, grasses, wood) and generate a stable product suitable for soil treatment (Guerrero and Monsalve, 2007; Wang et al., 2014). Specifically, composting is the result of microbial activity that converts organic matter to more stable humic forms and other inorganic products (e.g., carbon dioxide, water, ammonia, nitrates, methane) under controlled conditions, releasing heat as a metabolic waste product (Smith et al., 2017). To obtain a compost that can be used in agriculture, the humid organic solids must be oxidized to more biologically stable forms such as humus and comply with regulations (NTC 5167, 2011). Different researchers have studied the acceleration of the composting process through the use of microorganisms and their enzymatic machinery. The use of cellulite microorganisms has been studied due to their ability to decompose the cellulose of the plant material into smaller units that

are easy to degrade, which implies a more efficient and accelerated transformation of the composting material (Cepeda and Valencia, 2007). The use of lignolytic microorganisms is of great importance, since they do not completely mineralize the cellulose, but leave it in an intermediate state of decomposition and then repolymerize these compounds forming humic substances, reaching a material where the organic matter has not been lost, but it is stabilized in the form of recalcitrant molecules, which is what is important in a soil conditioner (Gonzalez et al., 2021). In this project, the production of a compost with pruning residues is proposed using *Pleurotus* spp as an accelerator of the process. Fungi of the genus *Pleurotus* are basidiomycete fungi of the order Agaricales (Aguilar et al., 2019), which are characterized by being efficient degraders of lignin present in plant tissues due to their ability to produce exoenzymes (Nadhim et al., 2017) such as laccase (Illuri et al., 2021; Akpınar and Urek, 2014). For this reason, and given the great lignolytic capacity of this fungus, the objective of this study focused on using the *Pleurotus* fungus as an accelerator of the composting process of pruning remains in the city of Barranquilla, as an alternative solution to the problem that involves the decomposition of these wastes in the open in the city's sanitary landfills. This study was carried out in municipality of Malambo, Atlántico, Colombia during 2020-2021.

## MATERIALS AND METHODS

### Location

The experiment to produce compost was developed in the facilities of the Energy Provider Company, located in the municipality of Malambo, department of Atlántico, Colombia (latitude: 10 ° 52' North and longitude 74 ° 47' West).

### Composting process

*Reception of raw materials.* The raw materials considered for the assembly of compost piles were bovine manure from the surrounding farms with a time not exceeding 5 days, pruning from the maintenance of the electrical networks of the city of Barranquilla and banana bagasse from the GRANABASTOS supply center. Numerous reports have presented the physical and chemical properties of bovine manure, which are important for composting. The moisture content goes from 13 to 75% weight (wt) (Font-Palma, 2019).

Elemental analysis (percent dry and ash-free basis) reported for cattle manure is 28 for carbon (C), 5.2 for (nitrogen (N) and the Carbon-nitrogen ratio (C/N) is 5.3. (Corro, et al., 2013).

#### *Pleurotus inoculum preparation*

The pruning was crushed and adjusted to a granulometry of 3 – 10 centimeter (cm) and packed in polyethylene bags of 2 kilogram (kg) closed with Polyvinyl chloride (PVC) tube plastic collars and pieces of bag. The substrate was steamed at 80°C for 2 hours (h). The inoculation was carried out by supplying in each bag with substrate 90g of *Pleurotus sp* seed acquired in campingfung under sterile conditions. Incubation took place in a closed room with an average temperature of 28°C and a relative humidity of 83.3% without lighting for a month.

#### *Assembly of composting piles*

Composting piles of 1 meter (m) high and 1 m wide were assembled with a content of 150 kg of material to be composted following the layered assembly methodology, distributed in three treatments (T) and a control according to an experimental design of random blocks with two repetitions for a total of 8 experimental units. The treatments were formulated as follows:

##### *Treatments 1 (T1)*

60% vegetable residue (51.7% new pruning - 15 days cutting + 8.3% banana bagasse) and 40% manure.

##### *Treatments 2 (T2)*

60% vegetable residue (50.39% new pruning - 15 days of cutting + 9.61% banana bagasse) and 40% manure. To this treatment was added or 5.8% of the total weight of the inoculum stack of *Pleurotus* in the mycelial state.

##### *Treatments 3 (T3)*

60% vegetable residue (50.39% old pruning - 1 month cutting + 9.61% banana bagasse) and 40% manure.

##### *Control*

60% manure and 40% vegetable residue (33.3% new pruning - 15 days of cutting + 6.7% banana bagasse) (Formulation proposed by the National

Education Service - SENA).

Throughout the process, the temperature and humidity of each composting pile was monitored for a period of five months. Once all the phases of the process were reached, a screening was carried out to establish the relationship between non-degraded residues vs the final product obtained using a sieve. Particles that did not pass through the sieve (equivalent to the non-degraded residue) and those that passed through the sieve (equivalent to the product obtained).

#### *Evaluation of quality parameters*

A sample was taken from each compost pile. The samples were analyzed in the laboratory of the University of Antioquia. The analyses carried out were: physicochemical analysis, heavy metal content, microbiological analysis, phytotoxicity and respirometry, according by the Colombian Technical Standard (NTC 5167, 2011) for compost.

#### *Biological efficiency test of the compost obtained*

To measure the effect of compost on plant growth, a biological efficiency test was performed. For the biological test, doses (in triplicate) of 100 gram (g) and 200 g of compost obtained from the eight composting piles were applied to corn seeds, sown in bags of 500 g capacity, for a period of 3 months, following a completely randomized experimental design and one control (without fertilizer). The soil used was the one used for construction, which is characterized by a low content of organic matter. At the end of the test, growth parameters were measured. At the foliar level, the area and total biomass were measured; at the fruit level, the number of cobs, length, weight, number and weight of the grains were measured. For the total leaf area, the length of each of the leaves per plant leaf x maximum leaf width x 0.75 was measured (García et al., 2020). For the determination of the total biomass, the leaves were cut, packed in kraft paper and dried in an oven at 70 °C to a constant weight.

#### *Data analysis*

The data obtained were subjected to an analysis of variance to determine significant differences in the mean percentage of degradation through the composting process between treatments. The null hypothesis (Ho) was contrasted that all treatments

formulated for the composting process had the same average percentage of degradation of plant waste vs the alternative hypothesis (H1) that at least a couple of formulations had a different average degradation percentage at a significance level of 5%. For the separation of treatments with similar effects was applied to the multiple-range test of Fisher's least significant difference (LSD). The analyses were carried out with the Statgraphics Centurion software.

## RESULTS AND DISCUSSION

### Raw materials

The analysis of the microbiological quality of the raw materials showed the presence of the phytopathogenic fungus of the genus *Phoma* in the pruning as well as the presence of nematodes in the used manure (Table 1). Despite this, raw materials of plant origin should only be free of phytopathogens of the genera: *fusarium sp*; *botrytis sp*; *rhizoctonia sp*; *phytophthora sp*. as well as phytopathogenic nematodes (NTC 5167, 2011). It is emphasized that it refers to a total count, not a count of phytopathogenic nematodes. Several authors emphasize that nematodes are one of the most abundant organisms in the soil, these microorganisms can be found as parasites in plants and animals; also, free-living nematodes (saprophytes) were found (Franco and Muñoz, 2004). This second group can be used as an indicator of the quality of soils due to the great diversity of species that exist (Sanchez and Talavera, 2013). Neither of these two types of microorganisms was evidenced in the final product for any of the treatments, which supports that the process reached the thermophilic phases (temperatures above 45°C) where pathogenic microorganisms are eliminated.

### Obtaining the compost

The null hypothesis (Ho) was contrasted that all treatments formulated for the composting process had the same average percentage of degradation of plant waste vs the alternative hypothesis (H1) that at least a couple of formulations had a different average degradation percentage. The analysis of variance showed that Ho is rejected ( $F(3,4)=17.55$ ,  $p\text{-value}=0.01$ ). The multi-range test showed that T2, in which *Pleurotus* inoculum was used as a differentiating factor, had an average degradation percentage of 41.7% ( $SD=1.7$ ) which is statistically higher than that obtained by the control, ( $M=25.7$ ,  $SD=0.9$ ) and treatment 1, ( $M=17.9$ ,  $SD=3$ ). It is found that by using *Pleurotus* in the composting process of vegetable waste of 15 days of cutting increases production by up to 24% approximately (Fig. 1). A similar result was obtained in the bioconversion of lignolytic residues using *Pleurotus sp*, with percentages close to 50%; stating that value exceeds the range of biotransformation in different waste treatments with *Pleurotus*, which ranges from 16.7% to 38.8% (Arias et al., 2005). According to the results obtained, when using *Pleurotus sp*. in the composting process, it manages to accelerate production in a period of 5 months, which is positive considering that composting is completed in approximately one year without this fungus (Arrigo et al., 2005). The acceleration of the process was due to the ability of the fungi of this genus to produce exoenzymes of high catalytic oxidoreductases such as peroxidases and oxidases, as well as intracellular enzymes such as hydroxylases, decarboxylases, dioxygenases, reductases and transferases (Del Cerro et al., 2021). On the other hand, many researchers (Jusoh et al., 2013; Sharma

Table 1: Quality parameters for raw materials

Organoleptic test				
Raw material	State	Color	Texture	
Pruning	Wet solid	Brown	Thick and heterogeneous	
Manure	Wet solid	Brown	Thick and heterogeneous	
Banana bagasse	Wet solid	Brown	Thick and heterogeneous	
Microbiological analysis				
Raw material	Mold UFC/g*	Yeast UFC/g	Nematodes and protozoa	Phytopathogen
Pruning	1,7 ± 0,4	0 ± 0,0	Not found	Phoma sp.
Manure	2,0 ± 0,1	0 ± 0,0	Found	-
Banana bagasse	2,2 ± 0,2	0 ± 0,0	Not found	-

\*Colony forming units per gram

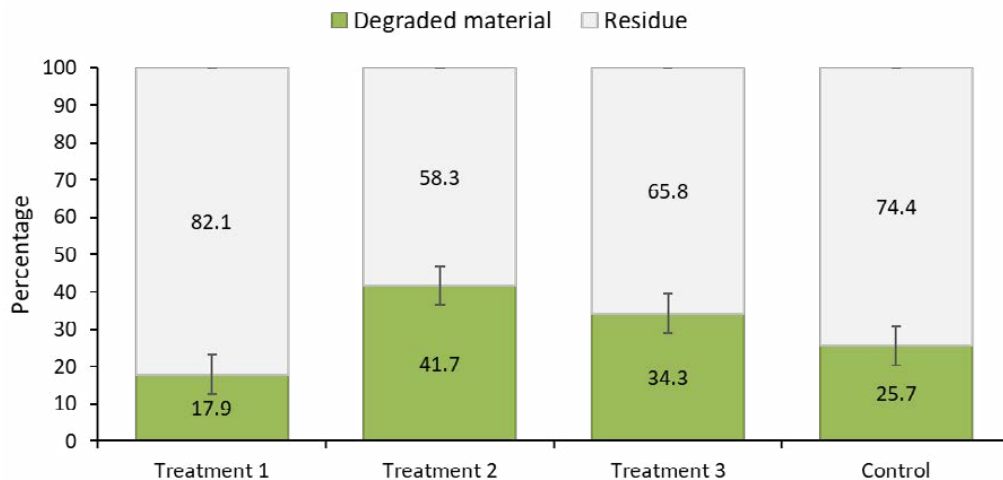


Fig. 1: Percentage of degraded material vs Residue per treatment

*et al.*, 2014; Karnchanawong and Nissakla, 2014; Zhao *et al.*, 2017) have used efficient microorganisms to accelerate the process (Rastogui *et al.*, 2020), but there are few studies focused on evaluating the quality of the product obtained according to the parameters established by the standard (NTC 5167, 2011).

The initial temperature in all the piles of the different treatments was close to room temperature, then it increased over time, which indicates that the reactive organic transformation process is exothermic. The maximum temperature reached in T1 was 53 °C, in T2 it was 60 °C, in T3 it was 58 °C and the control (treatment 4) was 44 °C, the latter being the one in which the temperature increased the least, since it was kept between 44 and 32 °C throughout the process. The temperatures were like those reached in other composting studies (Chaves *et al.*, 2019) other studies without fungal treatments and when depleted substrates with *Pleurotus* mushrooms are used in compost production (Hernández *et al.*, 2021; Gonzalez *et al.*, 2015). Aerobic composting is characterized by the predominance of aerobic respiratory metabolisms and by the alternation of mesophilic stages (10-40 °C) with thermophilic stages (40-75 °C), and with the participation of mesophilic and thermophilic microorganisms (Delgado *et al.*, 2019; Ajmal *et al.*, 2021). A low temperature in the pile is due to the fact that the size is very small, the wrong C/N ratio, lack of humidity and/or too much oxygen, based on these considerations T2 was the

one that was best oriented towards the formation of compost (Cardona and Hernández, 2008).

#### Physicochemical parameters

Most of the physicochemical parameters used to evaluate the physicochemical quality of the compost obtained in the different treatments were within the reference values established by NTC 5167, with the exception of the Cationic interchange (CIC) and ash parameters, which were slightly above the norm by 30 meq/100g approximately. This property is highlighted because is very important in the absorption of minerals, which is why it has a positive effect on plant growth (Table 2); (Sánchez *et al.*, 2019). Another parameter that was slightly above the norm was pH, registering values from 9.04 to 9.38 (acceptable pH of the NTC 5167 is 4-9), which suggests that the process had not yet fully matured, since during the composting process, this parameter behaves as follows: initially the pH drops, as a consequence of the fundamentally bacterial metabolism that transforms easily decomposable carbon complexes in organic acids; then, the pH increases as a consequence of the formation of ammonia, reaching the highest value, around 8.5, coinciding with the maximum activity of the thermophilic phase. Then, the pH decreases in the final or maturation phase (pH between 7 and 8) due to the natural properties of the organic matter buffer or buffer (Delgado Arroyo *et al.*, 2019). The great importance of this measure lies in the fact that this

parameter can affect crop production when applied to the soil, since it alters the pH of the soil and influences the absorption of heavy metals (Guerrero and Monsalve, 2007). Minimal concentrations of heavy metals were found (about 2-6 ppm), more specifically cadmium, nickel, and lead; all concentrations were under the established by NTC 5167. Although vegetable residues do not contain heavy metals, it is presumed that the heavy metals found come from exposure to automotive emissions and industrial gases from the city. As stated above, the vegetable waste comes from the city, which is exposed to all emissions. Other bioelements that contribute to plant growth, such as nitrogen, phosphorous, magnesium, zinc, potassium were also found in concentrations above 1% (Table 2). The humidity was also above the controlled parameters. None of the compost obtained showed the ideal humidity for the product (max. 35% for products of plant origin), which is due to the very nature of the pruning, which contains approximately 70%. Avoiding excess moisture is especially important for the destruction of pathogens during composting (Roy et al., 2021). Despite the moisture values obtained, in this research, the presence of pathogenic microorganisms

was not evidenced. The carbon/nitrogen ratio (C/N) was below the ideal (15-18), showing values around 11-12; this parameter determines the maturity of the compost (Albarracín et al., 2018). According to this result and the pH, it can be stated that the proposed treatment should increase the maturation time; on the other hand, this relationship was low due to the low percentage of oxidizable carbon in the product, which was <15%. With respect to particle size, 68% of the particles were smaller than 2 mm, which improves the performance of the reaction, since it increases the contact area between the reactive sites.

### Statistical analysis of the physicochemical and biological parameters

To establish similarities between the treatments, a multifactorial analysis of variance (ANOVA) was performed at 95% confidence. Statistical significance values (p) above 0.05 indicate that the treatments showed the same physicochemical and biological properties; in contrast, p values below 0.05 indicate that the treatments are different. The ANOVA analysis showed significant differences when comparing the treatments T1-T3, T1-control, T2-T3, and T1-control,

Table 2: Physicochemical parameters of the treatments

Parameter	NTC 5167	T1	T2	T3	Control
Aluminium (Al) total (%)		ND	ND	ND	ND
*Cadmium (Cd) total (pmm)	39	2,00 ± 0,08	0,80 ± 1	1,7 ± 0,3	1,75 ± 0,07
Calcium (Ca) total (%)		2,94 ± 0,06	14 ± 8	3,8 ± 0,5	3,3 ± 0,9
*Cromium (Cr) total (pmm)		0,02 ± 0	13 ± 13	9 ± 7	17 ± 11
Magnesium (Mg) total (%)		ND	0,96 ± 0,05	1,1 ± 0,4	0,6 ± 0,8
*Nickel (Ni) total (pmm)	420	6 ± 2	29 ± 7	30 ± 9	34 ± 15
**Lead (Pb) (%)	300	3 ± 1	2 ± 2	3 ± 1	4 ± 3
Potassium (K) total (%)		2,43 ± 0,01	2,3 ± 0,3	2,5 ± 0,2	2,5 ± 0,1
Sodium (Na) total (%)		2,5 ± 0,1	ND	ND	1 ± 2
Zinc (Zn) total (%)		ND	ND	ND	ND
**Ash (%)	60	68 ± 1	70 ± 2	69 ± 11	61 ± 9
*CIC (meq/100g)	30	61 ± 2	56,6 ± 0,6	58 ± 16	57 ± 9
CIC/CO (meq/100g)		510 ± 17	478 ± 79	424 ± 28	410 ± 146
** oxidable organic Carbon (%)	15	12 ± 0,9	12 ± 2	14 ± 3	14 ± 3
Electrical Conductivity		0,30 ± 0,01	0,18 ± 0,04	0,2 ± 0,1	0,3 ± 0,1
CRA (%)		108,6 ± 0,9	118 ± 17	112 ± 40	138 ± 32
*Density (g/cm <sup>3</sup> )	0,60	0,8 ± 0,1	0,7 ± 0,1	0,9 ± 0,1	**0,7 ± 0,3
Total Phosphorus (P) (%)		1,00 ± 0,03	0,54 ± 0,04	0,7 ± 0,3	0,62 ± 0,01
**Humidity (%)	35	54 ± 1	50 ± 2	51 ± 11	56 ± 5
*Total organic Nitrogen (N) orgánico (%)		1,43 ± 0,2	1,14 ± 0,07	1,2 ± 0,5	1,4 ± 0,3
**pH (10%)	4 - 9	9,27 ± 0,01	9,1 ± 0,2	9,0 ± 0,2	9,31 ± 0,02
C/N ratio		8,6 ± 0,3	11 ± 3	12 ± 2	11 ± 5
Particle size >2 mm (%)		38 ± 6	14 ± 9	30 ± 14	28 ± 14
Particle size <2 mm (%)		62 ± 6	86 ± 9	70 ± 14	72 ± 14

\*Parameters required by NTC 5167.

\*\* Parameters required by NTC 5167 values above or below the reference value.

while the treatments T2-control and T1-T2 were similar according to physicochemical properties. For its part, the ANOVA analysis for the biological parameters showed that all the p values are above 0.05, not refusing the null hypothesis that the treatments had equals biologicals properties (Table 3).

#### Microbiological quality of compost

The compost obtained in the different treatments complies with the parameters determined by NTC 5167. Table 4 shows that the parameters nematodes and protozoa, Enterobacteriaceae, and Salmonella

are absent or within the level accepted by said rule. Regarding the other parameters, the analysis found mesophiles and thermophiles in approximately 8E08 (UFC/100g), molds were found at a magnitude of 3, and in the final product were not found yeasts.

#### Phytotoxicity and respirometry of compost

The phytotoxicity of the compost was evaluated in radish seed, showing a decrease in the percentages of germination of the compost obtained in all treatments and the control, which means that it generates a toxic effect in this plant type (Table 5). The phytotoxicity

Table 3: Probability value at a statistical significance level of 95%

Combination	p-value (physicochemical parameters)	p-value (Biological parameters)
T1—T2	0,9154	0,7857
T1—T3	0,0002	0,0672
T1—CONTROL	0,0036	0,2486
T2—T3	0,0071	0,4594
T2—CONTROL	0,8131	0,9281
T3—CONTROL	0,0000	0,2719

Table 4: Microbiological parameters by treatments

Parameter	NTC 5167	T1	T2	T3	Control
**Mesophiles (UFC/100g)	----	1,8 E+08 ± 0,1	4 E+08 ± 1	6,4 E+08 ± 0,1	2,8 E+08 ± 0,4
Thermophiles (UFC/100g)	----	2,7 E+08 ± 0,9	5 E+08 ± 3	2 E+09 ± 2	1,7 E+09 ± 0,9
**Molds (UFC/100g)	----	4,0 E+03 ± 0,6	2 E+03 ± 2	2 E+04 ± 3	1 E+04 ± 1
**Yeast (UFC/100g)	----	0,00 ± 0,00	0,00 ± 0,00	0,00 ± 0,00	0,00 ± 0,00
Nematodes and/or Protozoa (Found/Not found)	Not found	Not found	Not found	Not found	Not found
*Enterobacteria (UFC/100g)	1000	2 E+02 ± 3	1,5 E+02 ± 2	6 E+02 ± 1	1 E+02 ± 1
*Salmonella (Found/Not found)	Not found	Not found	Not found	Not found	Not found

\*Parameters required by NTC 5167.

\*\* Parameters required by NTC 5167 values above or below the reference.

Table 5: Phytotoxicity and respirometry tests to treatments

Parameter	Unit	Treatment 1	Treatment 2	Treatment 3	Control
Phytotoxic at 2.5	% Germinación	40 ± 7	50 ± 0	60 ± 14	35 ± 0
Phytotoxic at 5.0	% Germinación	50 ± 7	53 ± 11	48 ± 11	38 ± 18
Phytotoxic at 7.5	% Germinación	48 ± 18	33 ± 18	43 ± 4	35 ± 21
Phytotoxic at 10.0	% Germinación	38 ± 18	48 ± 18	65 ± 7	15 ± 14
Parameter	Unit	Treatment 1	Treatment 2	Treatment 3	Control
Respirometry 24 hrs	mg CO <sub>2</sub> /g	0,28 ± 0,03	0,22 ± 0,06	0,2 ± 0,1	0,26 ± 0,00

is due to heavy metals presence or high salt content (Peña *et al.*, 2020), but the electrical conductivity values in this research were low. Regarding respirometry, the compost obtained in the different treatments presented values lower than 2 mg CO<sub>2</sub>/g total volatile solids (SVT), which means that the material is stable, does not continue decomposition, and does not produce odor (Soto and Meléndez, 2004).

#### Biological efficiency of fertilizers

The biological efficiency test of the fertilizers was carried out on corn seedlings. To evaluate the efficiency and effect of the compost several factors were measured, among them the foliar development (area and biomass) of the corn seedlings. The descriptive analysis showed a positive effect in some treatments and doses for the different parameters

evaluated compared to the control. Specifically, with doses of 100 g of compost from treatment 2, cobs with greater length were obtained, but for the rest of the parameters monitored with 100 g of compost obtained from treatment 3 achieved higher averages. In summary, the fertilizers of treatments 2 and 3 at a dose of 100 g per 500 g of soil were the ones that had the better biological results. Specifically, when treatment 3 was compared with the control, a notable difference was found, suggesting the proposed composting as a viable route for soil preparation for corn planting. Treatment number one in a dose of 100 g showed a lower effect than the control treatment, which indicates that this treatment supplied a lower amount of nutrients to seedlings, necessary for the development of the leaf area. This difference is due to the release of nutrients by the compost and the

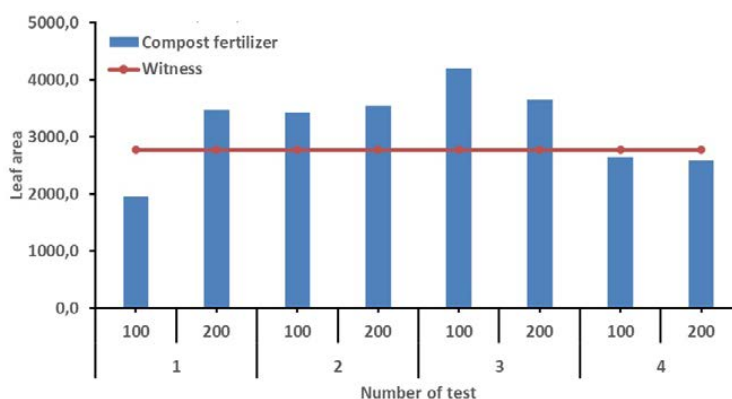


Fig. 2: Average total leaf area per treatments, a = 100g dose, b = 200g dose

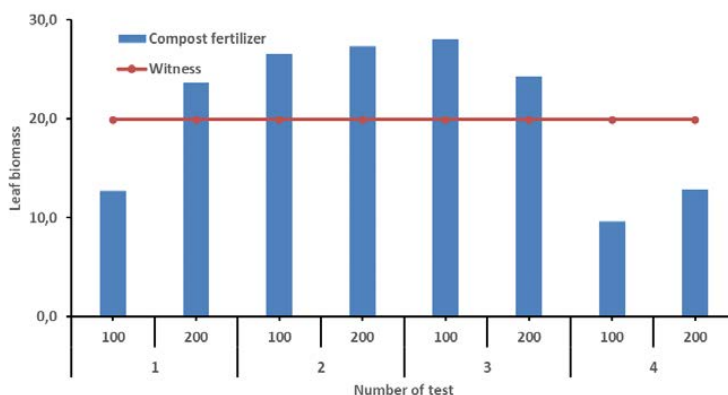


Fig. 3: Averages of total foliar biomass by treatments, a = dose of 100 g, b = dose of 200 g

subsequent absorption by the plants and due to the vital role of the compost application in improving soil properties (Asadu *et al.*, 2018; Zheng *et al.*, 2022). In a study conducted by Kadil *et al.* (2020) related to Potentials of organic manure and potassium forms

on maize (*Zea mays* L.) growths and production was observed a strong positive correlation between soil amendment (compost), and plant height, ear length, grains number/row, 100- grain weight (Figs. 2 to 7).

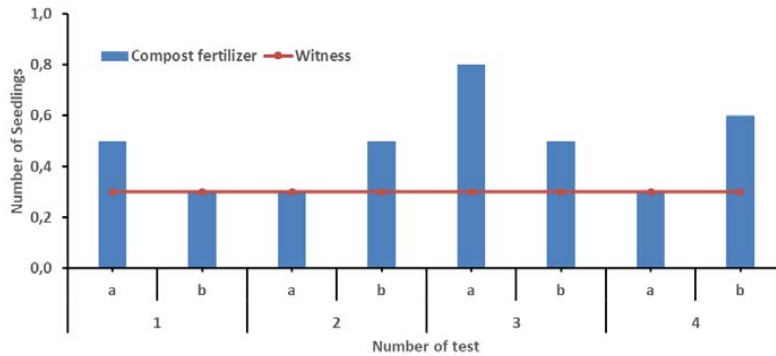


Fig. 4: Averages of the number of ears harvested by plants in each treatment, a = dose of 100 g, b = dose of 200 g

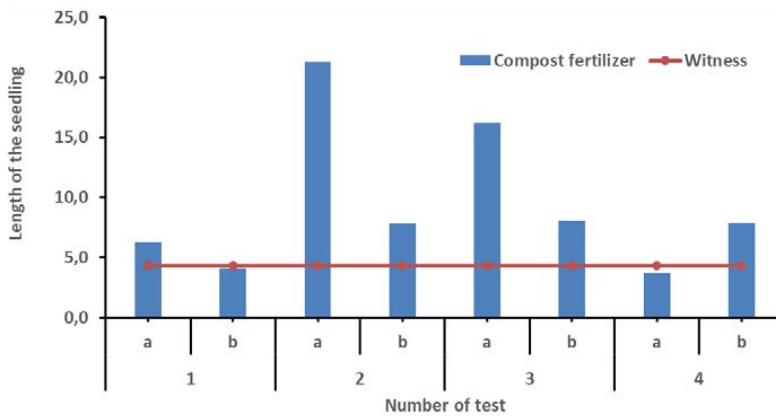


Fig. 5: Averages the length (cm) of the ears harvested in each treatment, a = dose of 100 g, b = dose of 200 g

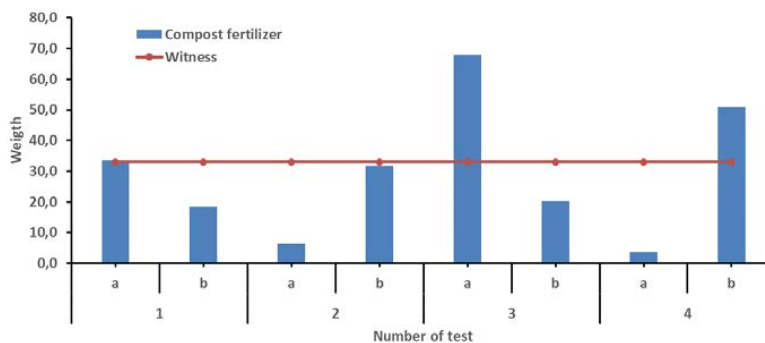


Fig. 6: Average weight (g) of the ears harvested in each treatment, a = dose of 100 g, b = dose of 200 g

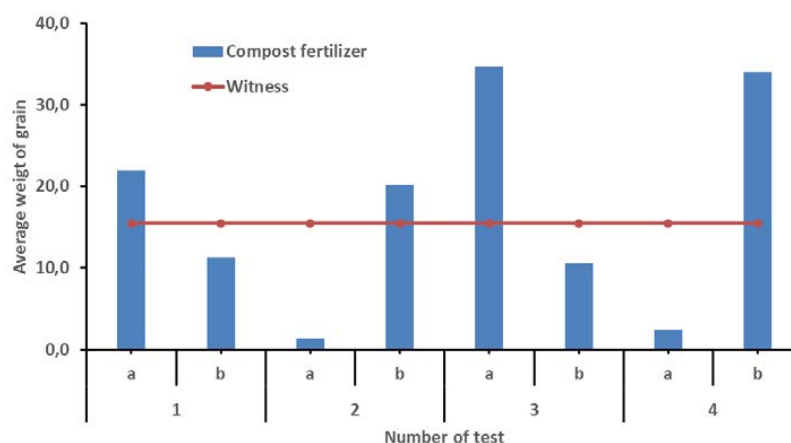


Fig. 7: Average weight of grain (g) of the ears harvested in each treatment, a = dose of 100 g, b = dose of 200 g



Fig. 8: Mycelial growth and fruiting bodies of *Pleurotus sp.* on pruning

#### Growth of *Pleurotus sp.*

As an additional result of this project, due to the experimental area reaching temperatures of up to 33°C and *Pleurotus* growing at 25°C (Barba et al., 2019), a good growth of the fungus was obtained under the environmental conditions of the region, evidenced in the great development of the fruiting bodies of *Pleurotus sp.* It showed that the pruning material could be a suitable substrate for the growth of this fungus of commercial interest due to its nutritional qualities (Fig. 8).

#### CONCLUSION

This study provides a solution not only for Colombia but for any other country that is experiencing strong pressure on its landfills that are

reaching their storage capacity and must generate urgent solutions for the management and use of organic waste. The volume of solid waste is one of the main problems, which in most cases ends up in landfills. In particular, large pruning residues would cease to be unusable waste and would be put to industrial use. Concerning the experiment, the fungus markedly accelerated the composting process and the compost yield obtained from pruning. Also, the fertilizer obtained notably stimulated the growth of the seedlings tested such as corn, this result was evidenced in terms of length of seedlings, weight of seedlings, leaf area, leaf biomass and other parameters. According to what was observed in the biological efficiency test for corn crops, it can be suggested that the proposed formulation, both

Treatment 2 and Treatment 3, can be used at an industrialized level with some adjustments. Another appreciated result was the abrupt growth of the fungus used as a process accelerator, which can be used for medicinal and food purposes. Considering the parameters regulated by the Colombian National Standard, most of the physicochemical and microbiological parameters monitored were within the value accepted by NTC 5167. Some the results showed a slight increase in pH and moisture, suggesting an increase in composting time. Sometimes it was necessary to adjust them to obtain statistically significant results in relation to the effect of the different treatments and the doses of compost applied. With respect to heavy metal toxicity, all of them are below the NTC 5167 standard, which is a very important result since the waste comes from an industrialized area and a high value could be expected. Biological parameters such as Mesophiles, Thermophiles, Molds, Yeast, Nematodes were under the allowable limit value established by standard. The process successfully eliminated the nematodes present in the manure used in the treatments. In summary, the solid organic residues from pruning and the formulations used in this research constitute an important raw material to produce fertilizer from composting, which could be used to stimulate the growth of agricultural plants. Further, the world economy is going through a conjunctural moment, states are promoting the development of applications within the framework of the circular economy, mainly aimed at the reuse of waste for the production of new materials. This method opens an opportunity for the development of usable materials in agriculture.

#### AUTHOR CONTRIBUTIONS

A. Medina-Buelvas performed the experimental design, sampling campaigns, compost quality analysis, interpreted the data and results, and prepared the manuscript text. A. García-Cuan made the fungal inocula and interpreted the data and results. B. Barraza- Amador Performed the biological efficiency assay, prepared the manuscript text and manuscript edition. E. Espinosa-Fuentes analyzed, interpreted the data and results, and prepared the manuscript edition. K. Mendez performed the experimental design, analyzed, and interpreted the data and results. M. Del Castillo monitored the process and prepared the manuscript text. N. Rosales managed

supplies, adaptation, and control of pilot plants.

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#### CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

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#### ABBREVIATIONS

°C	Degree centigrade
%	Percent
Al	Aluminium
ANOVA	Analysis of variance
Ash	Ash content determination
Ca	Calcium

<i>Cd</i>	Cadmium
<i>CIC</i>	Cationic interchange
<i>CIC/CO</i>	Cationic interchange on organic carbon
<i>cm</i>	Centimeter
<i>C/N</i>	Carbon-nitrogen ratio
<i>CO</i>	Oxidable carbon
<i>CO<sub>2</sub>/g</i>	Carbon dioxide per gram
<i>Cr</i>	Chromium
<i>CRA</i>	Capacity of water retention
<i>Fig.</i>	Figure
<i>g</i>	Gram
<i>g/cm<sup>3</sup></i>	Gram per cubic centimeter
<i>h</i>	Hours
<i>K</i>	Potassium
<i>kg</i>	Kilogram
<i>LSD</i>	Fisher's least significant difference test
<i>Max.</i>	Maximum
<i>Meq/100g</i>	Millequivalents per 100 grams
<i>Mg</i>	Magnesium
<i>mg</i>	Milligram
<i>mg CO<sub>2</sub>/g</i>	Milligram of carbon dioxide per gram
<i>mm</i>	Millimeter
<i>N</i>	Nitrogen
<i>Na</i>	Sodium
<i>ND</i>	Not detected
<i>Ni</i>	Nickel
<i>NTC</i>	Colombian technical standard
<i>P</i>	Phosphorus
<i>Pb</i>	Lead
<i>pH</i>	Hydrogen potential
<i>Pleurotus sp.</i>	Scientific name of fungus
<i>pmm</i>	Maximum allowable
<i>p-value</i>	Probability value
<i>PVC</i>	Polyvinyl chloride
<i>SENA</i>	National Education Service
<i>sp</i>	Specie
<i>SVT</i>	Total volatile solids
<i>T1</i>	Treatment 1

<i>T2</i>	Treatment 2
<i>T3</i>	Treatment 3
<i>UFC/g</i>	Colony forming units per gram
<i>wt</i>	Weight
<i>Zn</i>	Zinc

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## ORIGINAL RESEARCH PAPER

# Waste processing techniques at the landfill site using the material flow analysis method

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## ABSTRACT

**BACKGROUND AND OBJECTIVES:** Waste remains an issue in tandem with the development of the local community. The quantity of waste that is stockpiled in the landfill impacts the amount of leachate, resulting in emissions and reduced landfill capacity. The main challenge for its management is choosing the most cost-effective method to minimize leachate and emissions and increase the amount of waste that is stockpiled, resulting in a longer service life of the landfill. This study aimed to select the treatment at a landfill site.

**METHODS:** Field observations and sampling of waste composition were carried out at the Klaten Regency. Waste composition sampling was carried out over several years. Material flow analysis was used to calculate the amount of leachate, emissions, and waste in the landfills. The effectiveness and benefits of the treatment scenarios were compared.

**FINDINGS:** The waste consists of 55 per cent organic, 24 per cent plastic, 10 per cent paper, 3 per cent wood, 2 per cent cloth, 1 per cent glass, 1 per cent metal, and 4 per cent others. The processing scenarios were determined based on this composition. Four prospective scenarios were identified: 1) waste processing with composting; 2) composting and reuse, reduction, and recycling; 3) waste to energy; and 4) the combined process of scenarios 1 – 3. All treatments carried out can reduce leachate by 5.09 – 14.32 per cent, emissions of 11.31 – 44.48 per cent, waste 14.13 – 65.97 tons/day in the landfill, and can extend the service life of the landfill by 3 – 14 years.

**CONCLUSION:** Material flow analysis was used to calculate the waste processing, emission rate, and leachate production from the four processing scenarios. The reduction of leachate and emission was affected by the treatment used. Combined processing (scenario 2 or 4) can reduce leachate and emissions and extend service life. The selected processing alternative must also consider the benefit-cost ratio. Scenarios (2) and (4) have a benefit-cost ratio of more than 1, which means that the processing is feasible to implement. Scenario 4 has a higher investment cost; so, the scenario that can be applied to the Troketon landfill is scenario 2 with a small investment cost, capable of reducing polluters, extending the landfill's service life to more than 4 years, and a benefit-cost ratio of more than 1.

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## INTRODUCTION

The increase in population and the development of the economic level influence people's behavior, lifestyle, and consumption patterns (Laohalidanond et al., 2015). These behavioral changes also increase waste generation (Audina, 2018) and demand for management facilities. Municipal solid waste management (MSWM) includes collection, transport, processing, material and energy recovery, and final disposal (Martinez et al., 2012). The need for a sustainable form to maintain a clean environment and public health (Hoque and Ur, 2020). Solid waste management (SWM) in Indonesia still relies on the municipal solid waste landfill (MSWLF) as the estuary. The available MSWLF also becomes longer, less inadequate, and incurs high operational costs. Infrastructure development, specifically MSWM is slow. Out of approximately 69% of waste that goes to landfills, 10% has not been processed. Law No. 18/2008 concerning waste management mandated the use of a sanitary landfill system for waste disposal, in reality, many cities and districts continue to apply the open dumping technique (Lokahita et al., 2019). The Ministry of Environment and Forestry (2021) reported that 67.58% of waste has been managed by reduction and handling, while the remaining 32.42% was left unmanaged. Approximately 15.78% of the collected solid waste was reduced from the sources. SWM from the source is performed by reuse, reduction, and recycling. 51.8% of it is managed through storage, collection, transportation, and final disposal. Solid waste entering MSWLF comes from households, such as food or biodegradable solid, paper, plastic, and diapers (Kiddee et al., 2014). The limited land available for MSWLF affects its management, specifically disposal services. 60-70% of refuse could be transported and disposed of at MSWLF, while the remainder is improperly processed or managed (Effendy et al., 2012). The physical, economic, social, political, and institutional factors that influence SWM in different cities/regencies in developing countries necessitate a SWM system designed for their needs. Social, economic, and technological developments have also affected the increase in SWM (Al-Dailami et al., 2022). Developed countries have implemented the zero waste concept, which aims to change SWM practices, including household waste management, in a more sustainable direction due to their concern for environmental hygiene and health. The concept

includes solid waste prevention, recycling, recovery of all resources from solid waste, and behavior change (Cole et al., 2014). Waste in Indonesia is managed by transporting it into the MSWLF. This process produces leachate and landfill exhaust gases that can pollute the environment (Ratnawati et al., 2019). Leachate can contaminate surface water and groundwater (Mukama et al., 2016), whereas landfill gas can pollute the air and increase the potential for global warming (Sauve and Acker, 2020). The emissions from MSWM account for approximately 5% of all greenhouse gas emissions (Towa et al., 2019). Klaten Regency, Central Java, is one of Indonesia's districts with SWM problems. The MSWLF Troketon method is a controlled landfill system. Waste management in a regency is not optimal. The amount of accumulated solid waste reduces the lifetime MSWLF (Ratnawati et al., 2022). Gao et al. (2017) describes the integration of system dynamics (SD) and material flow analysis (MFA) into the circular economy theory to build a comprehensive framework based on regional economies. Ratnawati et al. (2022) reported landfill calculations using compost processing with predictions of waste generation. Markic et al. (2019) used material flow analysis for planning, based on separate collection and recycling. From previous studies, the novelty of this study is the material flow analysis used to compare the results of the effluent produced from the landfill using 4 scenarios. The 4 scenarios are scenario 1 using compost, scenario 2 using a combination of compost and reuse, reduce, recycle, scenario 3 process waste into energy, and scenario 4 combining compost, 3R, and waste to energy. This study aims to examine and compare several waste processing scenarios that can extend the service life of MSWLF by predicting the output produced in the form of leachate, emissions, and refuse stockpiled in the landfill using the MFA method. This study was conducted in MSWLF Troketon, Klaten Regency, in 2022.

## MATERIALS AND METHODS

This study was conducted in Klaten Regency, Central Java Province, Indonesia (Fig. 1) from February 2020 to May 2022. This location was selected based on the waste management problem at the MSWLF. Fig. 2 presents a flowchart of the study stages. The results obtained could be recommended for improving waste management at the final site in a regency.

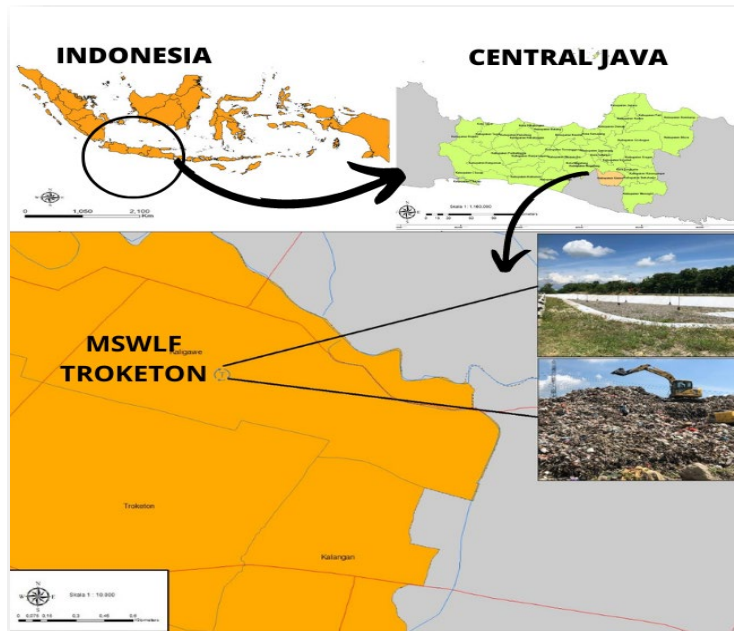


Fig. 1: Geographic location of the study area in Klaten Regency, Indonesia

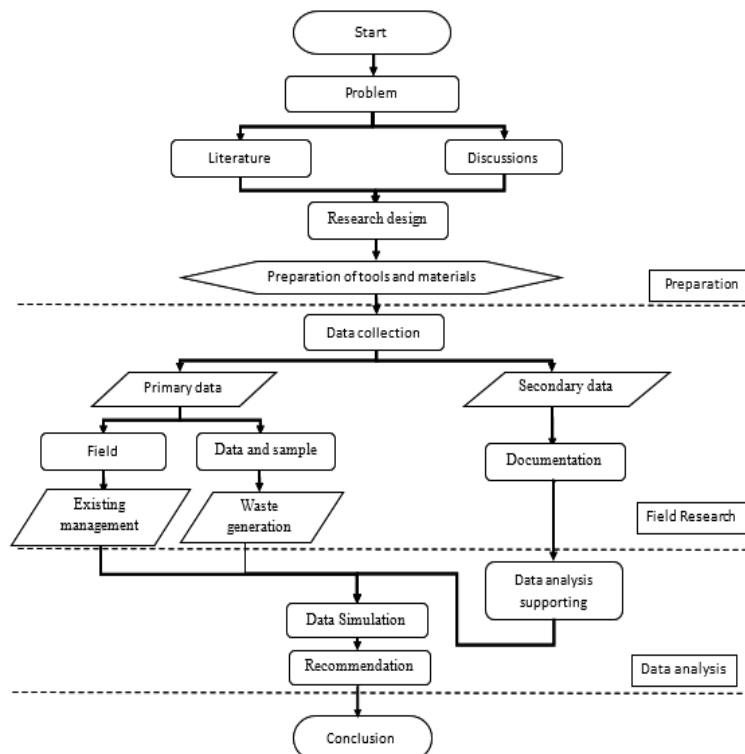


Fig. 2: Flow diagram for the overall methodology

### Sampling and waste composition

Waste sampling was conducted following the Indonesian National Standard (SNI) 19 – 3964 – 1994 regarding procedures for collecting and analyzing samples of the generation and composition of MSW. This study was performed in March and November 2020, March 2021, and April 2022. Random sampling of waste from trucks entering MSWLF was used, and a minimum of 3 trucks were collected. The waste taken is approximately 35-40 kg of waste/truck. It was obtained at random, then weighed up to 100 kg. Furthermore, the waste was sorted according to its type and weighed. Weight and volume measurements were performed based for each type of waste (Owusu-Nimo et al., 2019). The samples were separated into eight main categories: food waste, plastics, rubber, paper, textiles, non-combustible materials, wood, and other materials (Charkhestani and Kebria, 2022).

### Material flow analysis

The material flow analysis (MFA) method is used to determine the flow of waste and the products produced in the management model scenario (Markic et al., 2019). The flow started from the solid waste entering the MSWLF to the resulting output through the processing process. The model was created by processing the waste data entering the MSWLF, indicating that it can describe the flow of refuse products as well as the number of emissions and leachate produced. The output of the processed waste ( $Out_i$ ) is obtained by calculating the incoming waste ( $In_i$ ) multiplied by the percentage of processed waste ( $R_i$ ) was calculated using Eq. 1.

$$\sum Out_i = \sum In_i \times R_i \quad (1)$$

### Landfill life (Remaining life)

The useful life of a landfill can be calculated from the amount of stockpiled waste. The useful life

calculation determines the extent to which a landfill can be used. Waste processing in MSWLF can extend the service life by reducing the amount of solid waste that enters landfills using Eqs. 2 and 3 (Ratnawati et al., 2022).

$$\sum \text{waste with land cover} = \sum \text{waste to landfill} + (\sum \text{waste to landfill} \times \text{cover soil}) \quad (2)$$

$$\text{Remaining life} = \frac{\text{Capacity landfill}}{\text{waste with land cover}} \quad (3)$$

### Carbon emission

Waste management produces carbon emissions from landfilling, processing waste into compost, and waste processing by burning. The unusable carbon emissions in the landfills were calculated using Eqs. 4 and 5 and Table 1 (IPCC, 2019).

$$Lo = DDOC_m \cdot F \cdot \frac{16}{12} \quad (4)$$

Where:

$L_o$  =  $CH_4$  gas potential produced (Gg  $CH_4$ )

$DDOC_m$  = mass of degraded and decomposed organic carbon (kg)

$F$  =  $CH_4$  gas fraction from landfill gas produced.

$\frac{16}{12}$  = molecular weight ratio  $CH_4/C$

$$DDOC_m = W \cdot DOC \cdot DOC_f \cdot MCF \quad (5)$$

Where:

$DDOC_m$  = degraded and decomposed organic carbon (kg)

$W$  = mass of wet waste removed (kg)

$DOC$  = degraded organic carbon fraction

$DOC_f$  = decomposed organic carbon fraction

$MCF$  =  $CH_4$  correction factor on aerobic decomposition

Where:

Table 1: Value of  $DOC$ ,  $DOC_f$ ,  $MCF$ , and  $F$  from waste type (Towprayoon et al., 2019)

Waste type	$DOC$	$DOC_f$	$MCF$	$F$
Organic	0.15	0.7	0.5	0.5
Paper	0.4	0.5	0.5	0.5
Wood	0.43	0.5	0.5	0.5
Textile	0.24	0.5	0.5	0.5

Table 2: Waste generation in Klaten Regency from various sectors

Sector	Waste generation	
Total waste generation in Klaten Regency	378.15	Tons/day
Total waste transported to MSWLF	94.24	Tons/day
MSW generation rate	0.3	kg/individual/day
Domestic waste generation	1.3-1.5	kg/house/day
Waste generation from hotels, hospitals, Islamic boarding schools	0.0957	Tons/day
Market and commercial waste generation	7.57	Tons/day

### Leachate generation

Leachate is permeated water produced from solid waste heaps as well as being a solvent for harmful dissolved pollutants, especially organic solutes. Leachate can contaminate both soil and water. Proper processing is required to avoid leachate and environmental pollution. Equation 6 is the quantity of leachate generated (Youcai, 2018).

$$Q = I(C_1 A_1 - C_2 A_2) / 1000 \quad (6)$$

Where:

Q = quantity of leachate generation, m<sup>3</sup>/d

I = rainfall, mm / d

C<sub>1</sub> = leaching coefficient coefficient of operating landfill area (0.6)

C<sub>2</sub> = leaching coefficient coefficient of covered landfill area (0.6)

A<sub>1</sub> = operating landfill area, m<sup>2</sup>

A<sub>2</sub> = covered landfill area, m<sup>2</sup>

### Cost analysis

Waste management involves investment and operational costs. Operational costs consist of employee wages, fuel cost for heavy equipment, and waste-processing cost. Profit is derived from the sale of fertilizers, recycled goods, and generated energy. The benefit-cost ratio (BCR) was used to determine the feasibility of investment. A BCR ≥ 1 implies that the investment is feasible, but it indicates infeasibility when it is < 1, using Eqs. 7 and 8 (Chaerul and Rahayu, 2019).

$$\text{Operational cost} = \text{employee wage} + \text{fuel cost} + \text{heavy equipment} + \text{waste processing cost} \quad (7)$$

$$\text{BCR} = \frac{\text{profit}}{\text{Operational cost}} \quad (8)$$

## RESULTS AND DISCUSSION

### Description of the study area and context

Klaten Regency covers an area of 65,556 ha (655.56 km<sup>2</sup>) or 2.014% of Central Java Province (3,254,412 ha). Its territory covers all administrative regions, consisting of 26 sub-districts, 391 villages, and 10 sub-districts, with a population of 1,260,506 people based on 2020 data. Rainfall affects the degradation process of organic waste in landfills and impacts the amount of leachate produced. The regency has a tropical climate with alternating rainy and dry seasons, temperatures between 28-30 degrees Celsius, average wind speeds ranging from 20-25 km/hour, and the highest rainfall occurs in February 2020, which is 492 mm with 16 rainy days. The lowest rainfall was in July 2020, as much as 1 mm in 1 rainy day. The amount of waste produced in an area is influenced by the activities in the location, population, and economic growth sectors, such as education, tourism, health, and industry. There are 2,420 schools and colleges, 125 tourist attractions, 407 restaurants, 21 markets, 440 offices, 203 health facilities, 3,285 supermarkets/minimarkets/retails, 35,382 industries, 52 hotels, 5 Islamic boarding schools, and 56 settlements. These facilities are sources of waste in Klaten Regency and are generated from residents' domestic activities.

### Description of waste management in Klaten Regency

Waste management system includes storage, collection, transfer, transportation, and final disposal. Solid waste services have reached all subdistricts in the Klaten Regency. The Communal housing facilities in this region are shelters made of concrete/brick masonry. They are often found in schools, hospitals, housing, and settlements. There is 207 communal waste disposal ranging in sizes from 3 – 50 m<sup>3</sup> and 18 containers with a volume of 6 m<sup>3</sup> in the regency. Direct individual waste collection in this region is performed using a three-wheeled motorcycle and then transported directly to landfills. Indirect collection was performed using waste carts accommodated at temporary disposal sites. These carts were operated under the management of the village head. In the direct collection system, the generated waste is directly delivered by the source to a temporary communal shelter and then transported to MSWLF using a truck (Jimmyanto et al., 2018). Based on data from the environmental service of Klaten Regency

in 2021, an average of 94.24 tons of waste is sent to MSWLF in Klaten Regency every day.

#### Waste generation and composition at the study site

The waste generated in Klaten Regency originates from domestic and commercial activities. Domestic waste comes from residents, while commercial waste comes from markets and supermarkets. Table 2 shows the waste generated by various sectors in the regency. The amount of waste entering the MSWLF will continue to increase in 2016 - 2021, as shown in Fig. 3, and it is necessary to conduct processing to extend the service life. Alternative processing is determined by determining the composition of the waste generated at MSWLF. The waste from housing/settlements consists of plastic packaging, paper, organic materials (in the form of vegetable/food scraps), diapers, cloth, wood, glass, rubber, and others that are not included, whereas commercial waste is in the form of organic materials, plastic, paper, and wood (Fig. 4). The waste produced is predominantly organic; therefore, alternative processing can be performed in the form of composting. The treatment of waste, specifically organic material in compost, has not been widely conducted in the regency, as has occurred in various cities in developing countries (Thushari et al., 2020). Reuse, Reduce, and Recycle (3R) alternative processing to reduce waste. The amount of waste that enters MSWLF is reduced by scavenging activities (Sahwan et al., 2004). Scavengers

pick up inorganic waste such as paper, plastic, metal, glass, and rubber, which still have economic value to be used directly or sold to the industry as raw materials (Sarja, 2020; Tarigan et al., 2016). Solid wastes such as paper, plastic, and metal waste can be recycled into crafts. Paper waste can be recycled into art papers (Sahwan and Wahyono, 2002). Plastic waste is sold to the industry as plastic raw materials (Permatasari and Rahdriawan, 2013) and industrial fuel (Wahyudi et al., 2018). Metal waste such as used food cans can be easily separated from landfills, recycled into items of artistic value, re-melted back into the original material. It can also be used as a cement mixture (Anggraini et al., 2018). The role of scavengers is the key to reducing waste generation (Sasaki et al., 2014). Waste that cannot be processed through composting and 3R can be used as fuel for turbines, producing electrical energy. This process is known as Waste to Energy (WtE).

In Klaten, the quantity of MSW per capita is 0.3 kg/day, and the increase in the generation of Municipal solid waste is about 1.21%. The quantity of MSW per capita in Klaten is close to the quantity of MSW per capita in a rural areas of Yemen. Waste treatment in Sana'a, Yemen using composting and incinerators (Al-Dailami et al., 2022).

#### Description of waste management at MSWLF Troketon

The waste from the local shelter was transported

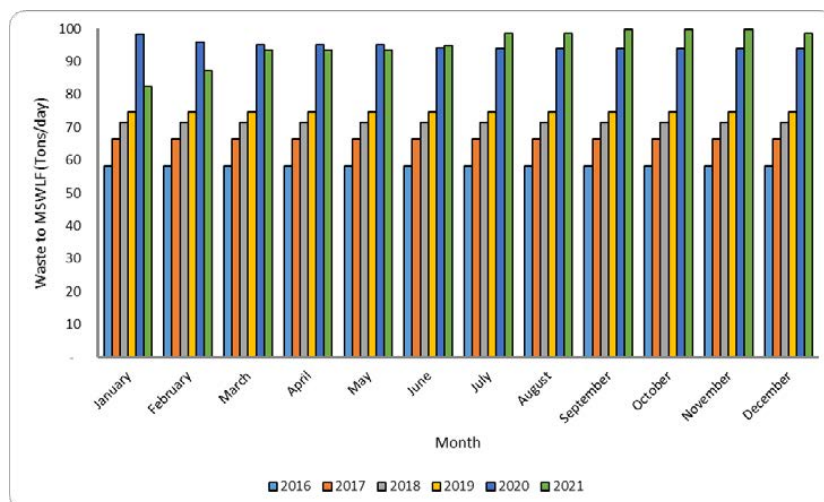


Fig. 3: Amount of waste that goes to MSWLF

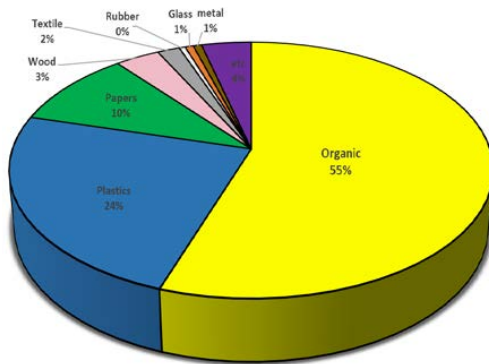


Fig. 4: Waste composition in MSWLF Klaten Regency

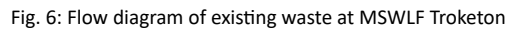
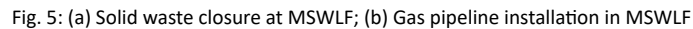
to the MSWLF Troketon for disposal at a landfill site. The type of vehicle is adjusted to the volume, location, distance, and ownership, including the tricycle, pick up, dump truck, or arm roll. MSWLF Troketon is located in the Pedan Sub-district. It has an area of approximately 7.08 ha, with 3 built-up zones. The area of zone 1 is 9,914 m<sup>2</sup> and the area of the zone 2 is 8,295 m<sup>2</sup>. The total capacity of zones 1 and 2 was 172,986 m<sup>3</sup>, of which 73% was used. The capacity of zone 3 is 74,623 m<sup>3</sup> which is used after zones 1 and 2 are filled. The final method for solid waste disposal is controlled landfill. The control landfill method applied in the Troketon landfill is that the solid waste entering the landfill is covered with soil every 3 days. The bottom layer of the landfill functions as a waterproof coating so that leachate does not seep into the soil, which results in the contamination of the soil and groundwater (Fig. 5). Landfill base coating materials are geotextile, and geomembrane can withstand the resulting leachate 477.93 m<sup>3</sup>/d. The geomembrane serves as a waterproof layer, and geotextile serves as the wear and reinforcement of the liner.

The minimum thickness of the geomembrane is 1.5 mm and above the geomembrane is layered with a minimum thickness of 4 mm of geotextile. The height of the landfill is 10 m above ground level, with the depth of stockpiling ranging from 3-5 meters. The embankment at the location of the landfill block with a slope of 45°. The waste that enters the MSWLF Troketon is weighed on the bridge and then the waste is weighed and sorted based on its organic and inorganic contents. 1.5 - 3 tons of waste has been composted but the implementation is not continuous owing to limited manpower. Inorganic wastes such as

plastic, textiles, paper, and metals are picked up by scavengers for recycling, reuse, or sale.

#### Waste management model at MSWLF

Waste management at the final processing site can be improved by implementing a hierarchy consisting of prevention, reuse, recycling, recovery, and landfill (Wang et al., 2020). This approach has been applied in several attempts to implement sustainable urban solid waste management (Kulkarni, 2020). Efficient segregation and integrated waste management are expected, which can minimize the burden of solid waste disposal on the ground (Abdulredha et al., 2020). Applicable integrated waste treatment consists of reduction, separation, transfer, recycling, recovery, and processing (Seng et al., 2018). Several alternatives for waste management development can be divided into two categories: intensification and extensification. Intensification is performed by reducing composting organic waste, recycling plastic, and processing waste technology into electrical energy (waste to energy). Extensification was conducted by expanding the land at the final processing site (Manurung et al., 2016). Urban solid waste, mainly organic matter, can be composted to preserve soil and reduce waste pollution (Khajuria et al., 2008). Urban waste management consists of compostable (40–60%) and inert materials (30–50%) (Kolekar et al., 2016). During the composting process, 75% compost products, 22% air emissions, and 3% leachate are released (Guo et al., 2019). Recycling is the process of planning, implementing, and controlling the efficient flow of goods and related information from the consumption point to the final processing site. This is where discarded electronic goods are collected and sent to recycling centers for recycling and final processing (Bellien et al., 2012). Waste processing into electrical energy (WtE) is the best solution for energy efficiency and the reduction of greenhouse gas potential (Liu et al., 2017) as well as the amount of stockpiled waste, thereby decreasing operational costs (Laner et al., 2019). The electrical energy produced is approximately 4% (Neehaul et al., 2019). WtE is an environmentally friendly processing technology that reduce waste (Mulyadin et al., 2018). It reduces the potential for global warming but has little economic impact (Maheshi et al., 2015). Landfilling produces methane gas, which can be processed into electricity (Verma et al., 2016) and



converted into electrical energy. In the existing waste flow chart, the percentage of leachate produced was 18.85%, whereas the emission is 75.39%, as shown in Fig. 6. Leachate emissions generated from landfill and composting then flown into leachate processing plant. The air emissions generated from landfill can be collected using a piping system.

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Compared to other types of treatment, WtE (Fig. 9) has an emission reduction value of 11.31% compared to the existing management. The combined treatment (Fig. 10) of composting, 3R, and WtE resulted in emission reduction and leachate values of 44.48% and 14.32% compared to the existing condition. Fig. 10 shows that the combined processing of composting and 3R's use of landfills to store unprocessed waste is significantly less than that of other processing alternatives.

Table 3 shows the current performance of MSWLF Troketon waste management and potential improvement scenarios. According to the table, scenario 4 is better than the others scenarios in terms of environmental and financial benefits. In addition, the processing of scenario 4 produces energy that

is utilized. The use of WtE in scenarios 3 and 4 not only produces energy but also requires installation costs and new equipment, as well as operating costs for utility consumption. WtE processing processes that can be used include gasification and combustion processes that require mechanical drying and installation of an initial thermal drying process that requires mechanical drying (Quan et al., 2022). Thermal treatment can be performed by combustion, gasification, or pyrolysis. Waste enters the combustion reactor during the combustion process. The heat generated in the reactor was converted into electricity (Quan et al., 2022). The combustion process produces flue gas and waste from combustion. Waste from combustion during pyrolysis is often called biochar, which can be used

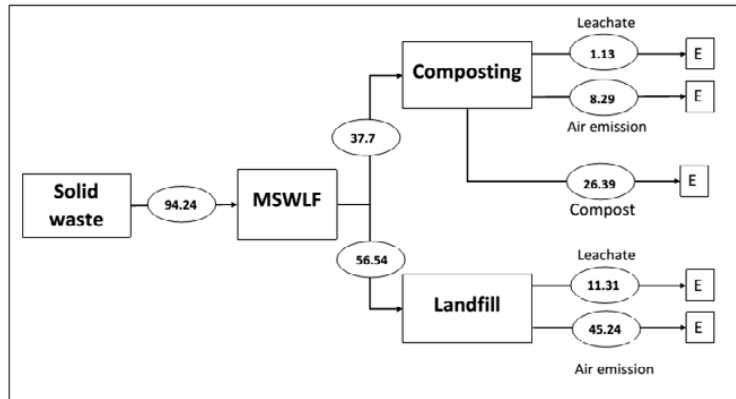


Fig. 7: Flowchart of compost processing (scenario 1)

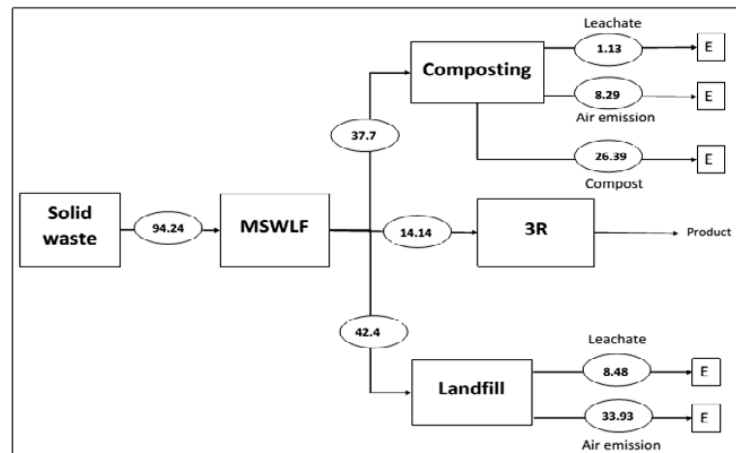


Fig. 8: Flowchart of compost processing and 3R (scenario 2)

for agriculture (Yavari et al., 2022). Scenario 3 and 4 the waste that enters MSWLF is processed into electricity with the characteristics of waste moisture content 47.4% weight, ash content 6.7% weight, volatile matter 45.6% weight and measured low heating value of 8.5 MJ/kg (MPWHRI, 2018). The processing scenarios can also be determined based on the social aspects and aspects of processing technical specifications. Social aspects are related to the effect of processing on the health of the surrounding community as well as the impact on the community's economy. Technical specifications are also used to determine the equipment capacity and processing efficiency.

Based on Table 3 scenario 1 has the lowest investment cost compared to other scenarios. Scenario 1 is able to extend the life of landfills longer and reduce pollutant greater than scenario 3. In addition, the benefit cost ratio of scenario 1 is was greater than that of scenario 3. The processing of scenario 3 produced more energy than scenarios 1 and 2. Scenario 2 is able to extend the landfill's service life by 2 years longer than scenario 3 and has a higher benefit-cost ratio than scenario 3. Scenario 4, compared to other scenarios is able to reduce polluters more, has the longest landfill life, is able to produce energy, and has the largest benefit-cost ratio but a high investment. Scenario four no can be implemented in Klaten Regency, because waste processing is also influenced by financing. Landfill financing in Klaten Regency comes from the Regional Expenditure Budget (REB); thus, financing for a year comes from the budget and submissions of the previous year and is based on the approval

of the Regional House of Representatives. Scenario 4 requires a large investment so that it cannot be met by the regional budget. Scenario 4 cannot be directly implemented in Klaten Regency. Financial aid from other parties must be prepared to implement this scenario. Scenario 2 was chosen because the resulting benefit-cost ratio has also reached 1.022%.

## CONCLUSION

The increasing amount of solid waste entering the MSWLF, the lack of segregation by type, and the technological constraints of waste processing in landfills are the primary issues with the management at the landfill site. The proposed solution is to sort and process waste at the MSWLF. There are four scenarios: waste processing with composting (scenario 1), composting and 3R (reuse, reduce, recycle) (scenario 2), waste to energy (WtE) (scenario 3), and combination of composting, 3R, and WtE (scenario 4). Scenario (1) can reduce leachate by 6.41%, and emissions by 21.86%. Scenario (2) can reduce leachate by 9.24%, and emissions by 33.71%. Scenario (3) can reduce leachate by 5.09%, and emission by 11.31%. Scenario (4) can reduce leachate by 14.32%, and emissions by 44.48%. Scenario 1 can extend the service life of the landfill to 2 years longer than the existing. Scenario 2 can extend the service life of the landfill to 3 years longer than existing. Scenario 3 can extend the service life of the landfill by 1 years longer than existing. Scenario 4 can extend the service life of the landfill by 12 years longer than existing. Processing scenarios 3 and 4 can generate energy but also incur a high investment cost. The results of scenario 4 (combination of composting,

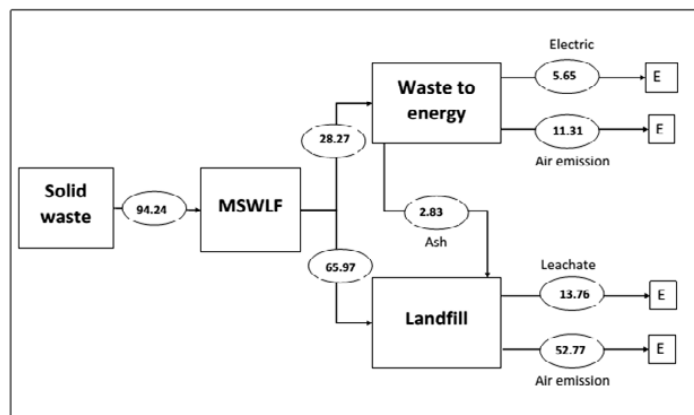


Fig. 9: Flowchart of WtE processing (scenario 3)

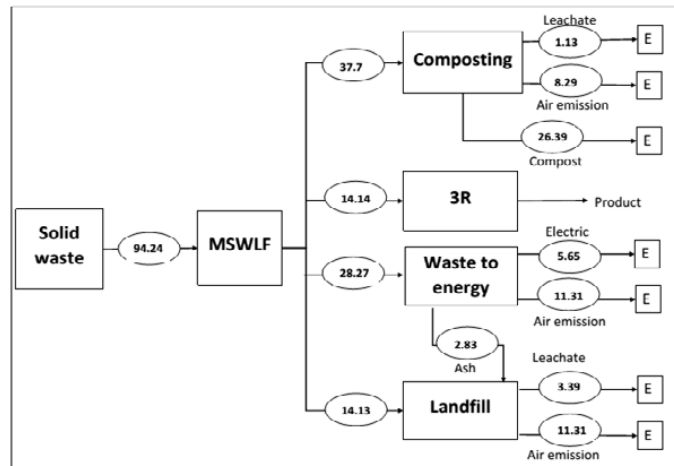


Fig. 10: Flowchart of combined processing (scenario 4)

Table 3: Performance of the existing waste management at MSWLF Troketon and improvement of the management scenario

No.	Criteria	Existing	Scenario 1	Scenario 2	Scenario 3	Scenario 4
1	The volume of waste at MSWLF (tonnes/year)	34,397.6	34,397.6	34,397.6	34,397.6	34,397.6
2	Volume of waste treated (tonnes/year)	0	13,760.5	18,921.6	10,318.55	29,240.15
3	Landfill life (years)	2	4	5	3	14
4	Carbon emissions (tons CO <sub>2</sub> eq/ton waste)	56.76	41.46	32.72	51.84	26.6
5	Energy gained (MJ/year)	0	0	0	13,183	13,183
6	Additional investment (IDR)	0	60,000,000	90,000,000	793,000,000	853,000,000
7	Processing cost (IDR/month)	1,245,428	1,275,349	1,375,349	1,295,428	1,335,349
8	Added value-profit (IDR/month)	-	1,023,981	1,406,218	938,823	2,345,041
9	BCR	0	0.803	1.022	0.725	1.756

3R, and WtE ) were the best among all the scenarios. This is indicated by the high pollutant reduction, long landfill life, large benefit-cost ratio, and energy generation. Scenario 4 cannot be applied directly to the Troketon landfill because of the high investment, so preparation and assistance from other parties are needed to make it happen. From this study, the selected scenario that can be applied to the Troketon landfill is scenario 2, which is a combination of compost and 3R. Material flow analysis can be used to analyze the four processing scenarios clearly, so that leachate flow, emissions, and stockpiled solids can be seen. The study gives insight into environmental aspects (reducing leachate and emission, and service life landfills), and economic aspect (additional investment, processing cost, value profit, and benefit-cost ratio). It is necessary to study processing scenarios based on social aspects and technical specifications to obtain comprehensive results for determining waste management in MSWLF.

#### AUTHOR CONTRIBUTIONS

A. Beata Ratnawati performed the sampling, data analysis, interpreted the data and results, and prepared the manuscript text. B. Mohamad Yani performed energy analyzed and played a role in coordinated the substance and publication of the research results. C. S. Suprihatin controlled the calculation result for the processing scenario. D. Hartrisari Hardjomidjojo control the interpretation of the model.

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## CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this paper. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication, falsification, double publication, submission, and redundancy have been completely addressed by the authors.

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## ABBREVIATIONS

$A_1$	Operating landfill area, m <sup>2</sup>
$A_2$	Covered landfill area, m <sup>2</sup>
$BCR$	Benefit – cost ratio
$C_1$	Leaching coefficient of operating landfill area
$C_2$	Leaching coefficient of covered landfill area
$cm$	centimeter
$CH_4$	Methane
$CO_2$	Carbon Dioxide
$DDOCm$	mass of degraded and decomposed organic carbon
$DOC$	degraded organic carbon fraction
$DOC_f$	decomposed organic carbon fraction
$E$	Emission
$Eq$	Equation
$Eqs$	Equations
$eq$	Equivalent
$F$	$CH_4$ gas fraction from landfill gas produced
$Gg$	Gigagram

$ha$	Hectares
$I$	Rainfall, mm/d
$IDR$	Indonesian rupiah
$IDR/month$	Indonesian rupiah/month
$In_i$	The incoming waste
$kg$	Kilogram
$kg/day$	Kilogram/ day
$kg/individual/day$	Kilogram/ individual/ day
$km/hour$	Kilometers/ hour
$kg/house/day$	Kilogram/ house/ day
$L_o$	$CH_4$ gas potential produced (Gg $CH_4$ )
$m^2$	Square meter
$m^3$	Cubic meter
$m^3/d$	Cubic meter / day
$mm$	Millimeter
$MCF$	$CH_4$ correction factor on aerobic decomposition
$MFA$	Material Flow Analysis
$MJ/kg$	Mega Joules /kilogram
$MJ/year$	Mega Joules /year
$MSW$	Municipal Solid Waste
$MSWLF$	Municipal Solid Waste Landfill
$MSWM$	Municipal solid waste management
$Out_i$	The output of waste processed
$Q$	Quantity of leachate generation, m <sup>3</sup> /d
$R_i$	Percentage of processed waste
$REB$	Regional expenditure budget
$SD$	System Dynamic
$SNI$	Indonesia National Standard
$SWM$	Solid waste management
$W$	Mass of wet waste removed (kg)
$WtE$	Waste to energy
$^\circ$	Degrees
$\emptyset$	Diameter
$\Sigma$	Total
$\%$	Percent
$3R$	Reuse, reduce, recycle
$16/12$	Molecular weight ratio $CH_4/C$

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## ORIGINAL RESEARCH ARTICLE

# Environmental effect of the Coronavirus-19 determinants and lockdown on carbon emissions

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## ABSTRACT

**BACKGROUND AND OBJECTIVES:** Coronavirus-19 has affected carbon emissions, which was declared as a pandemic by World Health Organization. Unprecedented environmental effects are being caused by Bangladesh's strict lockdown policies, which were implemented to stop the spread of Coronavirus-19. However, it is still unclear how the temporary halting and restart of industrial and commercial activities will affect the environment. In this study, it has been identified how Coronavirus-19 determinants like lockdown, daily confirmed cases, and daily confirmed deaths affect greenhouse gases.

**METHODS:** From March 18, 2020 to February 4, 2022 the data series is used for Bangladesh. To ensure that the data series were stationary, the Augmented Dickey-Fuller and Phillips-Perron tests were utilized. Johansen co-integration test was utilized to determine co-integration among variables. The Granger causality test was utilized to identify directional causes and effects between Coronavirus-19 determinants and carbon emissions and the Vector Error Correction Model was employed to determine short-run and long run connections.

**FINDINGS:** The study finds a bidirectional relationship between lockdown, carbon emissions and daily confirmed deaths, while a unidirectional association exists among Coronavirus-19 confirmed cases according to the Vector Error Correction Model. The Granger causality test also established the relationship between variables, except for daily confirmed cases. The pandemic's onset and subsequent lockdown resulted in decreased carbon dioxide emissions. The short-run link of carbon dioxide emissions with newly confirmed cases was corroborated by the directional relationship of variables, whereas there was a long-term and short-term association between confirmed deaths and lockdown.

**CONCLUSION:** The reduction in carbon emissions during the pandemic will not be long-lasting because it is anticipated that global economic activity will gradually return to the pre-Coronavirus-19 state. The directional and relational nature of lockdown offers the potential to connect carbon dioxide emissions to regular lives. During a lockdown, there is a connection between the atmosphere's changes and how natural organisms behave. Importantly, there is a room for investigation into how communities of organisms and the atmosphere would function without humans. The essential point is to stress that during the lockdown, the ecosystem is self-healing. Environmental activists and business people will find this study useful in developing future sustainable improvement strategies.

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## INTRODUCTION

In December 2019, Wuhan, China, faced a pandemic caused by an extremely infectious virus named coronavirus-19 (Covid-19) (Hui and Zumla, 2019). COVID-19 has had global quality of life and economic ramifications because of its long-term dissemination. Because of the COVID-19 susceptibility, the globe is on the verge of an unmanageable fatality rate. In order to limit the disease's transmission, most countries take some steps to tackle the spread of new emerging variants. According to recent research, successful viral control through widespread lockdowns has slowed the virus's transmission and enhanced the world's total quality of the environment indirectly (Sarfraz et al., 2021). In order to promote an active lifestyle, environmental quality is crucial. Toxic materials such as filth, smoking, intoxicants, and gases are all causes of environmental pollution. Carbon dioxide (CO<sub>2</sub>) emissions tend to be the most significant cause of air pollution. Extensive exposure to hazardous environmental circumstances has been proven to be damaging to one's health, with a significant number of people dying each year because of air contamination. CO<sub>2</sub> is a known source of health issues, and it is raising the death rate (Huang et al., 2017). Bangladesh's economy is growing rapidly and the country's industrialization is critical to its development (Mahmood, 2011). According to Bit Error Rate (BER), the industry contributes more than 35% of the gross domestic product and grows at a pace of 13% per year on average. Dhaka, Rajshahi, Chattogram, Narayanganj, Gazipur, and Khulna, for example, are home to nearly all these enterprises (Sabur et al., 2012). There is currently no systematic inventory of air pollution emissions in Bangladesh. In Bangladesh, transportation and chemical contaminants are the most major sources of pollution (Mahmood, 2011). For decades, Bangladesh has been classified as one of the most contaminated nations on the planet. Dhaka is routinely recognized as being among the most contaminated metropolitan areas in the world. According to IQAir (Swiss-based air quality technology company), Bangladesh is once again the most polluted nation in the world. In light of these facts, it is imperative to look into how COVID-19 cases and deaths are affected by Bangladesh's environment. The latest analysis on environmental quality in the world's 50 most congested areas was conducted by Rodriguez-Urrego and Rodriguez-Urrego (2020) and

claims Dhaka is the world's second most contaminated city with an estimated annual fine particulate matter (PM<sub>2.5</sub>) level of 97.1 gram per cubic meter (g/m<sup>3</sup>). Except for environmental efficiency and sustainability, COVID-19 has had an adverse influence on every aspect of life. To avoid the growth of COVID-19, the worldwide catastrophe people not to leave their houses. All major sectors like institutions, hotels, clubs, and restaurants in Bangladesh were shuttered during the near-global prohibitions. All less important commercial and social activities were closed during the lockdown in Bangladesh, which was enacted under the supervision of police personnel. The preliminary COVID-19 lockdown in Bangladesh helped people realize the severity of the sickness, prompting them to limit their mobility and as a result, influencing environmental circumstances. As a result, Bangladesh's lockdown steps were effective at preventing an increase in COVID cases while also enhancing the quality of the air in key cities throughout the region (Islam, 2020). People become less willing to properly dispose of and recycle their waste as they become more isolated in their homes. Environmental pollution as a result rises. Additionally, the restriction of staying in raises domestic waste, which puts more strain on the environment. As a result, the pandemic has an impact on environmental quality that is both positive and negative. Bangladesh is the world's most polluted country, with air pollution being a major concern. Because air pollution is uncontrollable, it has serious repercussions. Bangladesh has the weakest air quality index in 2020, ranking 162 out of 180 countries. In comparison to the same period in both 2018 and 2019, the air quality in 2020 during the lockdown improved. In comparison to 2018, the Air Quality Index (AQI) increased in 2019 by 9.00% and decreased by 9.57% in 2020. The AQI was discovered to be 16.74% lower in 2020 compared to 2019 when the two years were compared. During lockdown, air pollution decreased by up to 25–30% as a result of the closure of coal-fired power plants and other industrial operations. was discovered to have decreased by 36% during the COVID-19 spread out period compared to the same period in 2019, which may be attributable to a decrease in the use of fossil fuels and a ban on driving for vehicles to contain the virus's outbreak (Roy et al., 2020). In terms of pollution, it appears to have the worst performance (EPI, 2020). Carbon emissions are

mostly caused by open waste burning, automobile exhaust, and unregulated industrial effluents. Many individuals die each year as a result of the numerous illnesses linked to air pollution (Mahmood, 2011). Their findings suggest that during the global epidemic, environmental factors reduced harmful CO<sub>2</sub> concentrations, improving air quality (Rojas et al., 2021). It implies that the use of automobiles, mobility, and economic activity all affect the emission of atmospheric pollutants such as carbon dioxide. As a result of the stoppage of these operations during COVID-19, carbon dioxide levels have dropped dramatically. According to the findings, environmental protection might be achieved by satisfying environmentally friendly pledges, lowering financial realities and life risks, and promoting environmental practices (Ozturk et al., 2021; Rehman et al., 2021). During the global lockdown period, there was a huge reduction in air pollution. According to research, when the number of verified cases increased exponentially, policymakers in several countries imposed tight controls to prevent the virus from spreading (Higham et al., 2021). The government of Bangladesh has ordered a nationwide lockdown due to the severity of the COVID-19 outbreak. Bangladesh's government imposed isolation measures, travel restrictions, and the closure of markets, factories, and various businesses and institutions. People's daily life have been drastically altered as a result of the lockdown, ensuring that World Health Organization (WHO) requirements are strictly followed. The length of the shutdown however, is determined by the intensity of verified infections in different places. COVID-19, like other countries, forced Bangladesh to shutdown its factories, mass transit, and other anthropogenic activities. Because air quality is inextricably linked to emissions, which are primarily caused by open waste burning, automobile exhaust, and unregulated industrial effluents, a strict lockdown will result in improved air quality. Due to China's industrial shutdown, Isaifan (2020) reported a considerable reduction in N<sub>2</sub>O (nitrogen oxide) and carbon emissions (by 30 and 25 percent, respectively). As per recent statistics, 91% of the population lived in areas where the WHO has set minimum sustainability targets. As a result, this topic is extremely important to climatologists all around the planet. Moral conscience ensures a safe environment by reducing the emissions of smoke,

CO<sub>2</sub> and NO<sub>2</sub> into the environment. As a result, it is critical to provide a safe state of the environment as needed to shield the environment while also maintaining a comfortable atmosphere in which to protect a person's existence. A study was carried out in Bangladesh to highlight the socioeconomic consequences of COVID-19 (Islam et al., 2020; Shammi et al., 2020; Anwar et al., 2020; Tamang et al., 2020). Climate change has been linked to COVID-19 transmission in some studies that have been conducted in Bangladesh (Hriroy et al., 2020; Islam et al., 2020). However, no research on the COVID-19 lockdown's influence on air quality in Bangladesh has been conducted to our knowledge. Many people's societal structures and lifestyles were dramatically altered because of the COVID-19 epidemic. Furthermore, global mobility limitations and required inspections have influenced carbon emissions. The goal of this study is to determine the impact of contaminant constituents and carbon emissions over the COVID-19 timeframe. As a result, the study emphasizes the underlying relationship between COVID-19 and carbon emissions. The goal of the research is to figure out how annual carbon dioxide emissions affect COVID lockdown durations. This study emphasizes the importance of sustaining the current weather conditions even after the lockdown limitations have been lifted. As a result, the research allows governments to recognize the need for environmental stability while also improving the quality of the environment. Lockdown measures have been effective in reducing ambient levels of air pollution (Khan et al., 2020; Masum and Pal, 2020). According to the studies, COVID-19 has greatly improved air quality and air pollution caused by carbon emissions has decreased dramatically throughout the pandemic crisis (Sarfraz et al., 2021). Data spanning a few weeks to a few months, from the local to the global scale, was used in recent studies to examine how COVID-19-related activities affected air pollutants and GHG (greenhouse gas) emissions. Lockdown procedures generally still have a poor understanding of their importance and effects. As far as we are aware, no research has looked into how CO<sub>2</sub> emissions in Bangladesh have been impacted by COVID-19-related activities. Researchers looked into how COVID-19 determinants like lockdown, daily confirmed cases, and daily confirmed deaths affected greenhouse gas emissions. The main objectives of

this study, therefore, were to: i) investigate the effects of lockdown measures due to the COVID-19 pandemic on CO<sub>2</sub> emissions; and ii) investigate the effects of lockdown measures due to the COVID-19 pandemic on CO<sub>2</sub> emissions. The data series used covers Bangladesh from March 18, 2020, to February 04, 2022. This study has been carried out in Bangladesh in 2022.

## MATERIAL AND METHODS

Daily data on daily confirmed deaths, confirmed cases, and lockdowns are used to investigate COVID-19's influence on CO<sub>2</sub> emissions. Data was collected for this study from March 18, 2020 to February 4, 2022. The data is broken down into three sections: before the shutdown; during the closure (both strict and partial); and after the shutdown (Sarfraz et al., 2021; Khan et al., 2020). To prevent the pandemic, Bangladesh's government imposed a 10-day curfew on March 26, 2020, which was eventually extended until May 30, 2020. Bangladesh was subjected to its second full lockdown from April 5, 2021 to April 28, 2021 and its third partial lockdown from July 1, 2021 to July 28, 2021. COVID-19 confirmed cases and confirmed death statistics are collected by the Directorate General of Health Services (DGHS). The Carbon emissions data was provided by the US Consulate in Dhaka and the Bangladesh Meteorological Department (BMD). Fig. 1 has shown

the contribution of each study variables. In Fig. 1, this study used the natural logarithm of daily confirmed deaths (LNDD) and the natural logarithm of daily confirmed cases (LNDC).

From Fig. 1, it can be observed that carbon emissions decrease during the strict lockdown from March 20, 2020 to May 30, 2020; the same thing happens during the second full lockdown (April 5, 2021 to April 28, 2021); and the third partial lockdown (July 1, 2021 to July 28, 2021). To examine the link between lockdown, carbon emissions, daily confirmed death, and daily death, this study used a variety of statistical methods. The Augmented Dickey–Fuller (ADF) and Phillips–Perron (PP) tests are used to look for the unit root in time series data. By employing the Schwartz criterion, this research ran a typical Vector Autoregressive (VAR) model to get the best lag. After validating stationarity in the same order of data series, this work performed the Johansen co integration test. The Vector Error Correction Model (VECM) was used to assess short-run associations as well as the pace at which they were adjusted from short to long run. To check the direction of causality among the variables, this study used the Granger causality test. The methodological flowchart has shown in Fig. 2.

The lockdown is regarded as a dummy variable in this study (Sarfraz et al., 2021; Khan et al., 2020). The use of the dummy variable to assign the binary

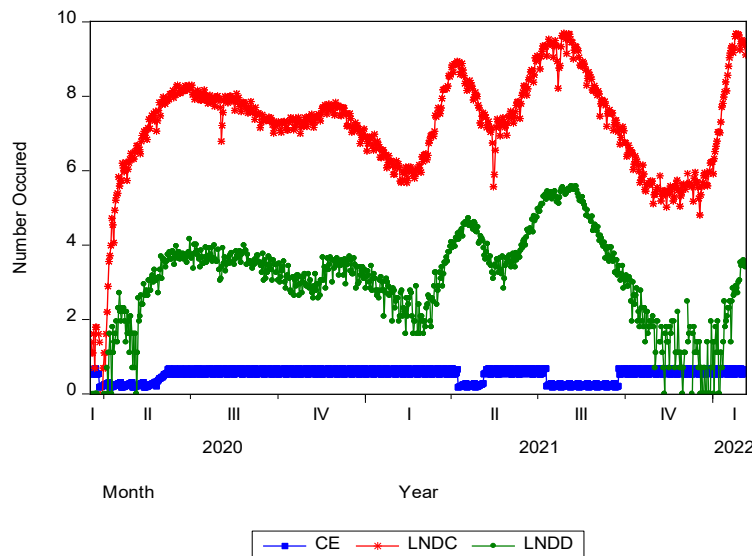


Fig. 1: Contributions of all the study variables

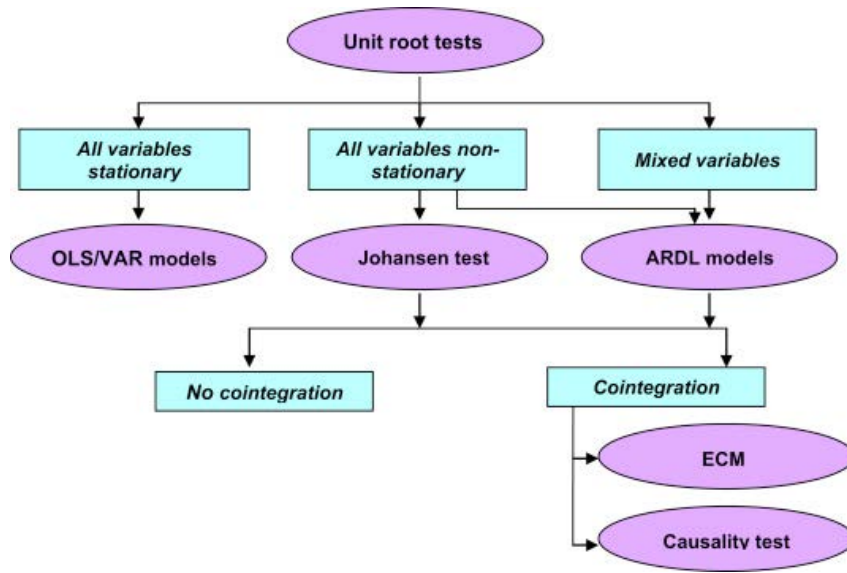


Fig. 2: The methodological flowchart

number is sensible; the lockout period has a value of 1 and the unlocked period has a value of 0.

#### ADF test

To determine whether the time series data has a unit root, an augmented Dickey–Fuller (ADF) test was used. The theoretical model is as using Eq. 1 (Cheung and Lai, 1995).

$$\Delta X_t = \alpha_0 + \alpha_1 t + \delta X_{t-1} + \sum_{i=1}^n \alpha_i \Delta X_{t-i} + \varepsilon_t \quad (1)$$

Where,  $\Delta$  is a first difference operator,  $X_t$  denotes any time series variables (economic growth, trade openness, and government final expenditure),  $\alpha_0$  is a constant,  $\alpha_1$  is a coefficient on a time trend,  $n$  is the lag order of the autoregressive process, and  $\varepsilon_t$  denotes the random error term.

#### PP test

For the PP tests, the test regression is using Eq. 2 (Rothe and Sibbertsen, 2006).

$$\Delta y_t = \beta_0 + \beta' D_t + \tau y_{t-1} + u_t \quad (2)$$

*Johansen's co-integration test*

For selected non-stationary and integrated first-order time series data, Johansen's co-integration test was used to determine the presence of co integrating vectors. The test is run using a vector auto-regressive (VAR) model, which is defined using Eq. 3 (Dwyer, 2015).

$$X_t = \alpha + A_1 X_{t-1} + \dots + A_p X_{t-p} + \mathcal{G}_t \quad (3)$$

Where,  $X_t$  is an  $(n \times 1)$ -dimension vector of variables  $\sim I(1)$ , and  $\mathcal{G}_t$  is an  $(n \times 1)$ -dimension vector of innovations.

Therefore, Eq. 3 can be re-written using as Eqs. 4, 5 and 6 (Dwyer, 2015).

$$\Delta X_t = \alpha + \Pi X_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \Delta X_{t-i} + \mathcal{G}_t \quad (4)$$

$$\text{Where } \Pi = \sum_{i=1}^p A_i - I \quad (5)$$

$$\Gamma_i = - \sum_{j=i+1}^p A_j \quad (6)$$

If  $\Pi$  has the rank  $r < n$ , then there will be  $(n \times r)$  matrices  $\gamma$  and  $\delta$ , both having rank  $r$  in a way that  $\Pi = \gamma \delta'$ , whereas  $\delta' X_t$  is stationary. Two likelihood ratio tests (LRTs) utilized to test the significance of the

reduced rank of  $\Pi$  are defined as below.

#### Trace test

Here, the null hypothesis of  $r$  cointegrating vectors is tested against the alternative hypothesis of  $n$  cointegrating vectors. The corresponding test statistic is defined using Eq. 7 (Dwyer, 2015).

$$\zeta_{trace} = -N \sum_{i=r+1}^n \ln(1 - \hat{\zeta}_i) \quad (7)$$

Where,  $N$  is the sample size and  $\hat{\zeta}_i$  denotes estimated eigenvalues ranked from largest to smallest.

#### Maximum eigenvalue test

Here, the null hypothesis of co integrating vectors  $r$  is tested against the alternative hypothesis of cointegrating vectors  $r + 1$ . The corresponding test statistic is defined using Eq. 8 (Dwyer, 2015).

$$\zeta_{max} = -N \ln(1 - \hat{\zeta}_{r+1}) \quad (8)$$

Where,  $N$  and  $\hat{\zeta}_i$  are defined the same as for the trace test.

#### VECM model

The Johansen's co-integration test was used, which shows that if two or more series are co-integrated, causality exists between them. It is based mostly on a VECM, which includes using Eq. 9 (Hansen and Seo, 2002).

$$\begin{bmatrix} \Delta CE_t \\ \Delta DC_t \\ \Delta DD_t \\ \Delta LD_t \end{bmatrix} = \begin{bmatrix} \mu_1 \\ \mu_2 \\ \mu_3 \\ \mu_4 \end{bmatrix} + \begin{bmatrix} B_{11i} & B_{12i} & B_{13i} \\ B_{21i} & B_{22i} & B_{23i} \\ B_{31i} & B_{32i} & B_{33i} \\ B_{41i} & B_{42i} & B_{43i} \end{bmatrix} \begin{bmatrix} \Delta CE_{t-i} \\ \Delta DC_{t-i} \\ \Delta DD_{t-i} \\ \Delta LD_{t-i} \end{bmatrix} + \begin{bmatrix} \theta_1 \\ \theta_2 \\ \theta_3 \\ \theta_4 \end{bmatrix} [ECT_{t-1}] + \begin{bmatrix} \gamma_{1t} \\ \gamma_{2t} \\ \gamma_{3t} \\ \gamma_{4t} \end{bmatrix} \quad (9)$$

Where,  $CE_t$ ,  $DC_t$ ,  $DD_t$ , and  $LD_t$  are carbon emission, daily confirmed cases, daily confirmed deaths and lockdown.  $ECT_{t-1}$  is an error-correction term.

Two different tests have been implemented based on the sources of causation as follows:

(a) Short-run causality specifies the underlying association between the time series variables in the short-run, determined through a merged test of the coefficients based on both the  $F$ -test and the  $\chi^2$  test.

(b) Long-run causality specifies the underlying association between the time series variables in the long run, which is tested through lagged Error Correction Term (ECT) in the VECM based on a  $t$ -test.

#### The Granger causation test

The Granger causality test establishes the bidirectional association between the variables by adhering to two fundamental principles: The consequence comes before the effect, and the cause holds unique insight into future values. The Granger causality test is estimated using Eqs. 10 and 11 (Guilkey and Salemi, 1982).

$$X_t = \beta_0 + \sum_{j=1}^k \beta_{1j} X_{t-j} + \sum_{i=1}^m \beta_{2i} Y_{t-i} + \varepsilon_{1t} \quad (10)$$

$$Y_t = \alpha_0 + \sum_{u=1}^p \alpha_{1u} Y_{t-u} + \sum_{h=1}^n \beta_{2h} X_t + \varepsilon_{2t} \quad (11)$$

If estimated parameter  $\beta_{2i}$  is statistically significant,  $\beta_{2i} \neq 0$  then  $Y \rightarrow \text{Granger cause } X$  and vice versa.

## RESULTS AND DISCUSSION

The Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests were used in our empirical study. Table 1 summarizes the study's findings.

The Akaike information criterion (AIC) was used to find the best lag structure. CO<sub>2</sub> emissions, COVID-19 determinants, and PM<sub>2.5</sub> levels are all constant at their current levels. According to the ADF and PP tests, all variables are I (0). The results of both tests suggest that the variables are I (1) because the study variables are stationary at first difference. According to Bahmani-Oskooee and Bohl (2000), the long-run connection is determined by the model's appropriate lag section. Using the traditional vector autoregressive (VAR) model, the optimal lag was calculated. The automatic lag specification, which

Table 1: Unit root test results

Variables	Level		First Difference	
	ADF	PP	ADF	PP
DC	-2.4123**	-3.7845**	-3.8745**	-25.1236**
DD	-2.9956**	-1.3625**	-6.5241**	-38.4125**
LD	-2.9237**	-3.2581**	-26.2545**	-26.1452**
CE	-3.4125**	-7.1584**	-6.8745**	-36.7120**

\*\* refer significant at 5% levels of significance. For optimal lag, order SIC is used, and constant and time trend are included in level and first difference.

Table 2: VAR model for optimal lag selection

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-9505.826	NA	1009363.	28.01421	28.04750	28.02710
1	-6335.424	6284.774	95.58583	18.74941	18.94914	18.82672
2	-6211.132	244.5566	71.34815	17.45694*	18.82312*	18.59869
3	-6173.943	72.62535	68.83402	18.42104	18.95366	18.62722
4	-6151.543	43.41363	69.36710	18.42870	19.12776	18.69931
5	-6043.882	207.0787	54.38128	18.18522	19.05073	18.52026
6	-6002.224	79.51039	51.78429	18.13615	19.16811	18.53563

\*indicates lag order selected by the criterion; LR: sequential modified LR test statistic (each test at 5% level); FPE: Final prediction error; AIC: Akaike information criterion

SC: Schwarz information criterion; HQ: Hannan-Quinn information criterion

Table 3: Unrestricted co integration rank test (trace) and maximum Eigen statistics

Unrestricted Cointegration Rank Test (Trace)					Unrestricted Cointegration Rank Test (Maximum Eigenvalue)				
Hypothesized	Eigenvalue	Trace	0.05	Probability	Hypothesized	Eigenvalue	Max-Eigen	0.05	Probability
No. of CE(s)	Eigenvalue	Statistic	Critical Value	P-value**	No. of CE(s)	Eigenvalue	Statistic	Critical Value	P-value**
None*	0.1179	116.95	47.85	0.0000	None *	0.117	85.85	27.58	0.0000
At most 1*	0.0215	31.09	29.79	0.0352	At most 1	0.021	14.87	21.13	0.2977
At most 2*	0.0147	16.22	15.49	0.0388	At most 2	0.014	10.17	14.26	0.2006
At most 3*	0.0088	6.046	3.84	0.0139	At most 3 *	0.008	6.04	3.84	0.0139

Trace test indicates 4 cointegrating eqn(s) at the 0.05 level

\* denotes rejection of the hypothesis at the 0.05 level

\*\*MacKinnon-Haug-Michelis p-values (acquired by software)

Max-eigenvalue test indicates 2 cointegrating eqn(s) at the 0.05 level

\* denotes rejection of the hypothesis at the 0.05 level

\*\*MacKinnon-Haug-Michelis p-values (acquired by software)

is “2,” is chosen using the AIC Criterion (Sarfraz et al., 2020). The findings of Standard VAR model have shown is Table 2.

Table 3 summarizes the findings of the co integration test. The co integration test is used to determine whether variables have a long-term relationship. The trace test and max eigenvalues are further elaborated by the Johansen co integration test. The null hypothesis  $r=r^* < k$  was severely rejected by the trace test, but the alternative hypothesis  $r=k$  was accepted. The null hypothesis of max eigenvalues is like that of the trace test, except that the alternative is  $r=r^* +1$ . Under “all”

conditions, the significance and co integration were confirmed, showing a 4-cointegrating equation at a 1% significance level. Under the “none” and “at most 3” conditions, the maximum eigenvalues are also significant, indicating two co integrating equations at a 1% significance level.

The findings of the trace and max eigenvalues test results are shown in Table 4. The long-run nexus between variables can be double-checked using this co integration equation. Although the nature of the relationship is negative and positive, the co-integration equation confirms the long-run link. The daily confirmed COVID-19 instances and the lockup

Table 4: Co-integration coefficient normalized

1 Cointegrating Equation(s)		Log likelihood	-6218.428
Normalized cointegrating coefficients (standard error in parentheses)			
CE	DC	DD	LD
1.000000	1.01E-05	-0.000630	0.392854
	(4.9E-06)	(0.00032)	(0.02649)

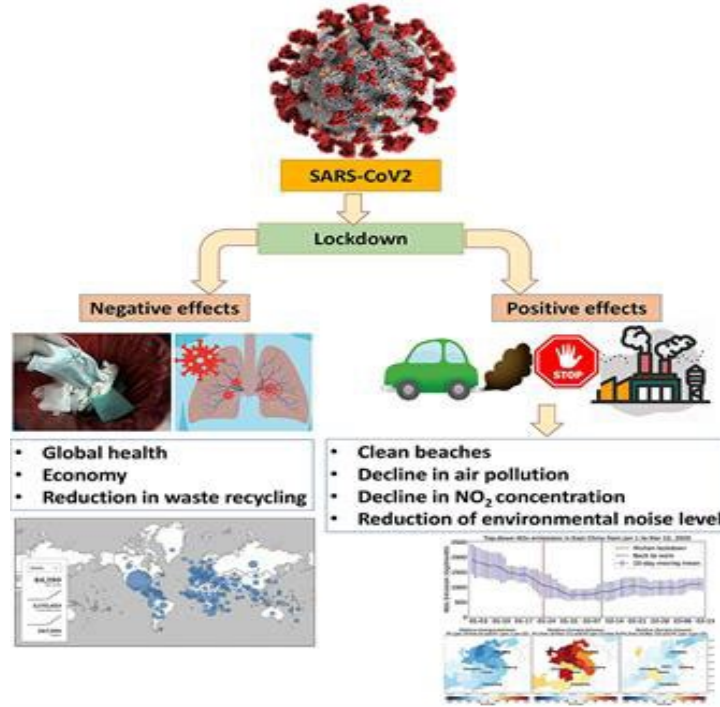


Fig. 3: COVID-19, lockdown and the effects on the world  
(Kumar *et al.*, 2020)

have revealed a downward trend in carbon emissions. The daily-confirmed deaths, on the other hand, show a downward trend in carbon emissions.

COVID-19 has both beneficial and negative environmental implications, as shown in Fig. 3. The VECM results are shown in Table 5, which detail the short- and long-run associations as well as the causative direction of each variable separately. The short run and long run results of vector error correction model has shown in Table 5.

The 3<sup>rd</sup> difference of carbon emissions is bidirectionally related with daily confirmed death indicates that,  $CE_3 \rightarrow DD_3$  at 5% level of significance. Carbon emissions is unidirectionally related with lockdown at 2<sup>nd</sup>, 3<sup>rd</sup> and 4<sup>th</sup> difference indicates

that  $CE_{234} \rightarrow LD_{234}$ . The negative value of -2.04 shows that strict lockdown reduced the carbon emissions by 2.04% (Sarfranz *et al.*, 2021; Andreoni, 2021). At 4<sup>th</sup> difference bidirectional relationship is observed between the carbon emission and lockdown (Rehman *et al.*, 2021). At the 1%, 5%, and 10% levels of significance, daily confirmed cases at the first, second, third, and fourth difference have unidirectional and positive links with carbon emission (Amankwah-Amoah, 2020; Rume and Islam, 2020). On the other hand, daily confirmed cases and daily confirmed death are bidirectionally related with 1<sup>st</sup> and 3<sup>rd</sup> difference indicates that  $CE_3 \leftrightarrow DD_1$  and  $DC_3 \leftrightarrow DD$  at 1% level of significance. Daily death has

Table 5: Vector error correction for short-run and long run estimates

Error Correction	Short run				Long run
	$\Delta CE$	$\Delta DC$	$\Delta DD$	$\Delta LD$	$ECT_{t-1}$
$\Delta CE - 1$		-822.3177	-16.38405	0.058511	
$\Delta CE - 2$		69.87103	-14.17230	-2.043243**	
$\Delta CE - 3$	----	-120.3471	-6.151469*	-1.048555*	-0.211106*
$\Delta CE - 4$		-364.1135	-2.722536	3.034546*	
$\Delta DC - 1$	1.35E-06*		0.001427*	8.14E-06	
$\Delta DC - 2$	4.36E-06**		-0.000686	-3.56E-06	
$\Delta DC - 3$	8.59E-07**	----	7.48E-05*	4.53E-06	-122.7422
$\Delta DC - 4$	2.48E-06***		-0.000865	3.46E-06	
$\Delta DD - 1$		0.000248		0.000223	
$\Delta DD - 2$	2.67E-05	6.876815**		0.000616	
$\Delta DD - 3$	-0.000336**	4.220957*	----	0.000160	16.29079*
$\Delta DD - 4$	0.000299	-0.414999		0.001042***	
$\Delta LD - 1$	0.021667	-35.88643	2.014360		
$\Delta LD - 2$	0.025130	-415.4054**	-2.813864	----	-0.041968**
$\Delta LD - 3$	-0.014291	646.9145**	0.294615		
$\Delta LD - 4$	0.032560***	-189.3730	-7.601609**		
C	-0.000177	18.85935**	0.074174	-0.000326	

\*, \*\*, and \*\*\* are representative of 1%, 5%, and 10% levels of significance, respectively.

Table 6: The Granger causality test

Direction of causality	df	Chi-square	p-value
DC	4	9.23347**	0.0274
DD	4	12.87452*	0.2030
LD	4	5.69321	0.0021
ALL	12	22.36521*	0.0020

\*, \*\*, and \*\*\* are representative of 1%, 5%, and 10% levels of significance, respectively.

negative unidirectional link with carbon emissions at 3<sup>rd</sup> difference at 5% level of significance. At 10% level of significance lockdown has positive link with the carbon emissions at 4<sup>th</sup> difference. The long run cointegration results also shown in Table 5. The findings indicates that except daily confirmed cases all variables have long run relationship. At 1% level of significance carbon emissions and daily confirmed death and at 5% level of significance lockdown are significant for the long run. To investigate the causality among the study variables, Granger causality test has performed, and the results has been shown to Table 6. The connection patterns are discovered by examining empirical data sets for probabilistic causality theories. At 1% level of significance, carbon emissions, lockdown, daily confirmed deaths, and daily confirmed cases have all shown the significant link. Because the mortality rate is very certainly based on new verified cases, the newly confirmed fatalities have no bearing on the cross-check results.

This outbreak is expanding, and people aren't getting good medical care yet, but none cannot predict how long it will last. As the death rate declines, medical professionals around the world continue to work on developing a proper therapy or vaccination.

Carbon emissions, COVID-19 daily confirmed cases, COVID-19 daily confirmed deaths, and lockdown are all stationary at the first difference, according to the ADF and PP tests. (Sarfranz et al., 2021; Rume and Islam, 2020). This study have chosen lag "2" by using standard VAR model employing AIC Criterion. Johansen co integration test such as Trace test and maximum eigen value test confirmed cointegration among the study variables. The COVID-19 lockup and daily confirmed COVID-19 incidents have showed a decrease trend in carbon emissions. On the other hand, daily confirmed deaths show a declining trend in carbon emissions. According to the VECM model, the third difference in carbon emissions is bidirectionally associated to a daily confirmed mortality at a 5%

level of significance in the short run. At the second, third, and fourth differences, carbon emissions are unidirectionally connected to lockdown. Strict lockdown reduced carbon emissions by 2.04%, as indicated by the negative number of -2.04. COVID-19's death has increased the number of confirmed cases. As if the new confirmed instances will increase the death rate, which is almost guaranteed to happen (Long and Li, 2021). Except for daily verified instances, the findings show that all factors have a long-term association (Abbasi et al., 2021; Sarfraz et al., 2021). Carbon emissions and daily confirmed deaths are significant at a 1% level of significance, and lockdowns are important at a 5% level of relevance in the long run. Examining empirical data sets for probabilistic causality theories reveals the link patterns. The lockdown, new verified COVID-19 cases, and carbon emissions all exhibit strong connections, implying that the link is still active. CO<sub>2</sub> emissions are mostly caused by significant energy consumption in daily transportation, trade, industrial activity, and other activities (Tian et al., 2022; Yang et al., 2021). The COVID-19 global epidemic is first and probably most important a global serious health hazard with serious health and economic consequences, but it has also had positive effects on the environment that could serve as an example and encouragement for future changes in behavior that will help us achieve positive changes in the environment (Jia et al., 2021; Bar, 2021; Bray et al., 2021). The present worldwide pandemic has pushed us to pause and consider alternative scenarios. The lockdowns demonstrate that a cleaner environment is feasible (Ray et al., 2021; Nguyen et al., 2021; Rugani and Caro, 2020). The global epidemic is revealing a link between pollutant emissions and major economic activities like manufacturing, transportation, and energy production, as well as tiny disruptions at the city level. As a result, suitable techniques for preventing environmental degradation should be implemented. The lockdown gives people confidence that human intervention in the environment can be minimized. Governments and individuals should use the tactics mentioned below to make positive changes in the environment (Khan et al., 2021) as: 1) Transportation management and safety checks; 2) Trains or buses i.e., public transportation, that runs smoothly; 3) Enhancing transit planning; 4) Using environmentally friendly products; 5) Chlorofluorocarbons (CFCs)

should be used even less than conceivable; 6) Biofuels are increasingly being used; 7) supporting garbage recovery and recycling; 8) Neonicotinoids are being used less frequently; 9) Avoid the use of toxicants as much as possible; 10) Do not waste water unnecessarily; 11) Reforestation; 12) Before sewage enters the environment, it is treated and solid, suspended, and inorganic pollutants are removed. COVID-19 demonstrated that the world was ill-prepared to handle an increase in medical waste, but it also offers a chance to address a challenge that has substantial ramifications for reducing climate change, combating pollution, and developing robust medical systems. Strengthening systems to safely and sustainably reduce and manage medical waste is possible in light of the COVID-19 waste challenge and the pressing need to address environmental sustainability (Ray et al., 2022). Strong domestic rules and practices, regular measuring and reviewing, public transparency, support for behavior change and employment services, as well as increased budgets and financing, can all be used to achieve this. The use of sustainable packaging and shipping, safe and reusable personal protective equipment (PPE), recyclable or biodegradable materials, investments in non-burn waste disposal innovations, such as sterilizers, recycled content to support centralized treatment, and investment opportunities in the recycling industry to ensure components, like plastic products, can have a second life are all recommended (Nicolini et al., 2022). The current study has a few limitations. Daily completed tests, the number of clinical isolates, public resistance, internal migration, and other human behaviors, as well as cultural and economic factors, can all complicate COVID-19 transmission, and these factors were not considered in the study. Another limitation is that this study only look at Dhaka, the capital of Bangladesh. The study findings are also relied on data from the outside meteorological environment, which is one of the study's significant shortcomings. SARS-CoV-2 transmission, on the other hand, can be influenced by the environment.

## CONCLUSION

The impact of the COVID-19 determinant and lockdown on carbon emissions was investigated in this study. The cointegration test verifies the long-term link between the chosen variables. According

to the VECM model, there is a short-term and long-term relationship (bidirectional or unidirectional) between carbon emissions, daily confirmed deaths, daily confirmed cases, and lockdowns. The findings backed up the theory that lockdowns cause a reduction of carbon emissions. The existence of a relationship between study variables is established by the Granger causality test. Granger causality results have revealed that daily confirmed COVID-19 cases are of no consequence. During the COVID-19 incident, certain critical lessons were learned as outlined in this study. For human survival and existence, the environment is a very crucial factor. For a sustainable ecosystem, this research advises that governments, legislators, and corporations minimize harmful gas emissions. The findings of this study, on the other hand, will be valuable to policymakers and other management authorities in devising effective solutions to solve air pollution and global warming challenges. The study is significant because it can predict the association between air pollution and associated atmospheric variables such as reduced atmospheric temperature and greenhouse gas emissions. Future research on urban heat islands and their impact on overall environmental sustainability can benefit from the findings of this study. Because air pollution is one of the key drivers of urban heat islands, future studies on urban heat islands should consider this. To reduce emissions of significant air pollutants, urban planners should adopt suitable measures, such as lowering traffic congestion, enforcing the odd-even vehicle rule, vowing to drive one day less per week, and imposing tough rules for the toxic industry. During this COVID-19 lockdown period, governments and global environmentalists acknowledge that various shutdowns are required to break the cycle of future viral infections. The world also realized that environmental protection and ecological sustainability serve as primary deterrents to outbreaks. To avoid future pandemics, a sustainable ecosystem must be achieved. In terms of greenhouse gas emissions, the lessons learned from COVID-19 can be applied to the rest of the world. Global transportation, climate, and environmental policies that encourage carbon emissions must be changed, and concerned authorities must work hard to do so. Overall, the results give stakeholders and decision-makers guidance for creating and putting into action carbon emission control measures that

will support a green life.

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#### **AUTHOR CONTRIBUTIONS**

The study conceptualization, methodology, software, data analysis and validation were performed by R. Parvin. F. Tuj Johora performed the draft preparation. A. Alim performed the visualization and reviewed and editing the paper.

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#### **CONFLICT OF INTEREST**

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

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## ABBREVIATIONS

%	Percent
ADF	Augmented Dickey–Fuller
AIC	Akaike Information Criterion
AQI	Air quality index
BER	Bit error rate
BMD	Bangladesh Meteorological Department
CE	Carbon emissions
CFCS	Chlorofluorocarbons
CO <sub>2</sub>	Carbon- di-oxide
COVID-19	Coronavirus -19
DC	Daily confirmed cases
DD	Daily confirmed deaths
DGHS	Directorate General of Health Services
GHG	Greenhouse gas
HQ	Hannan–Quinn information criterion
EPI	Experimental Performance Institute
FPE	Final prediction error
IUBAT	International University of Business Agriculture, and Technology
IQAir	Swiss-based air quality technology company
Lag	lagging behind
LD	Lockdown
LNDC	Natural logarithm of daily confirmed cases
LNDD	Natural logarithm of daily confirmed deaths
Log	Logarithm
LR	sequential modified LR test statistic
LRT	Likelihood ratio tests
NO <sub>2</sub>	Nitrogen Dioxide
N <sub>2</sub> O	Nitrogen oxide
PM <sub>2.5</sub>	Fine particulate matter
PP	Phillips–Perron
PPE	Personal protective equipment
SARS-CoV-2	Severe acute respiratory syndrome coronavirus 2
SC	Schwarz information criterion
WHO	World Health Organization

VAR	Vector Autoregressive
VECM	Vector Error Correction Model

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ORIGINAL RESEARCH ARTICLE

## The role of knowledge, awareness and environmental attitudes in green product management

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### ABSTRACT

**BACKGROUND AND OBJECTIVES:** Manager involvement is very important in environmental protection. Since then, many managers have integrated environmental sustainability into their business strategies by adopting green practices that focus on green products. The aim of the current study is to examine the effect of environmental knowledge on green products and the mediating role of environmental awareness and environmentally friendly attitudes.

**METHODS:** This study used a structured questionnaire for collecting data, where respondents were asked to provide their responses to green products produced by environmentally friendly manufacturing companies. The partial least squares structural equation modeling was used to test and analyze the relationships in the proposed model.

**FINDINGS:** The results of the study explained that in order to create a green product, managers' awareness of the environment needs to be formed which can be realized by the presence of a number of knowledge about the environment. Thus, environmental awareness is a mediator between environmental knowledge and green products. However, an environmentally friendly attitude is not a mediator between environmental knowledge and green products.

**CONCLUSION:** Managers' awareness of the environment must be realized by sharing knowledge about the importance of protecting the environment because this will affect the production of green products.

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## INTRODUCTION

In the 21<sup>st</sup> century, there has been an increase in environmental problems. For this reason, companies are required to use balanced natural resources through responsible behavior from both the community and the business world, thus economic development can be achieved, and negative environmental impacts can be minimized from economic activities and obtain social welfare (Pinskaya et al., 2021; Yumei et al., 2021; Babenko et al., 2019), which ultimately forms sustainable development. Popularity and priority of sustainable development in most business circles focused on human development and environmental protection (Gryshchenko et al., 2022). Since then, more companies are integrating the environmental concerns in their business operations and in their interactions with stakeholders, embracing environmental sustainability into business strategies. Moreover, they are increasingly adopting green practices. The reason is to increase competitiveness and be social responsibility. The term of green is usually used to describe environmental protection and quality improvement (Raharjo, 2018; Xie et al., 2019). Green practices in companies generally focus on clean technologies including cleaner production, eco-efficiency of materials, renewable energy technologies, and efficient energy utilization (Espinosa et al., 2021; Hu et al., 2022). Since the early 2000s, the focus of sustainable companies has shifted from the introduction of clean technologies to the production of green products (Fernando et al., 2019). In general, green products are used to describe products that seek to maintain and protect the environment during the production process by conserving resources and minimizing waste and pollution (Sana, 2020; Ouhsine et al., 2020). There were many studies on green products from a consumer perspective (Sharma and Foropon, 2019; Choi and Johnson, 2019; Redman, 2014; Kautish and Sharma, 2020; Bansal, 2011). However, Katsikeas et al., 2016; Albino et al., 2009 have conducted quantitative research on the perceptions of company managers about green products. Green products are influenced by external influences from consumers. Nonetheless, internal influences such as knowledge, awareness, and attitude of managers towards green products cannot be neglected, as decisions made by managers that significantly affect the company's

image are coupled with the help of their subordinates. In addition, studies investigating the mediating role of environmental awareness and attitudes from a manager's point of view are still limited. Based on the description of previous studies, it can be seen that this research contributes to filling the gaps in the literature. Karatas and Gürbüz, 2016; Osman et al., 2016 found that environmental awareness mediates the effect of environmental knowledge on environmentally friendly attitudes and green products viewed from the perspective of consumer. In contrast to the previous researches, the novelty of this research is investigating the environmentally friendly awareness and attitude which mediate the relationship between environmental knowledge and green products from the manager's perspective. The decision to produce products is the main focus and responsibility of the manager. Therefore, it is very important to further investigate the role of managers in green product. The development of green products requires environmental knowledge (Li et al., 2019). Based on this, it is important for managers to have knowledge of the environment which consists of: systemic knowledge, knowledge related to action, and knowledge of benefits (effectiveness) (Geiger et al., 2018). Systemic knowledge is knowledge of the existence of environmental problems. Action-related knowledge is knowledge of the impact of behavior on the environment and knowledge of benefits (effectiveness), knowledge of tools for how to reduce environmental impacts. It can be said that in order to overcome environmental problems, individual must first carry out systematic knowledge, where this knowledge analyzes before taking action and must have an understanding of the natural state of the ecosystem and the processes in it. Individual should not just overcome the environment which ultimately destroys the ecosystem of it. What can be done to overcome environmental problems is by doing some efforts to keep the environment, thus the benefits of environmental work process can be realized. Therefore, in carrying out activities, company managers must know the process of environmental knowledge which starts from the analysis, action, and benefits of environmental knowledge. In addition, environmental knowledge is the most important aspect of environmental awareness (Zsóka et al., 2013; Zhan et al., 2018). This means that with environmental knowledge possessed by individuals,

environmental awareness will be formed because the result of environmental knowledge is environmental protection science and insight that is useful for forming environmental awareness. Thus, individuals who have some environmental knowledge will be more concerned and sensitive to environmental damage compared to individuals who do not, thus, care and love for the environment does not appear. Environmental knowledge and awareness is very important for the prevention of environmental problems. To form environmental awareness, a multidimensional concept is needed which consists of cognitive, affective and conative components (Du *et al.*, 2019). The cognitive component is the basis for pro-environmental behavior because this component consists of environmental knowledge such as the ability to overcome environmental issues, the affective component of environmental awareness includes feelings or emotions expressed as well, bad, positive, negative, likes, dislikes, anger, not angry, and others. For example, individual will be frustrated and angry when the industry pollutes the environment. It can be said that the affective component as a predictor of pro-environmental behavior. Finally, the conative component of environmental awareness is behavioral intentions that contribute to solving environmental problems. In this study, environmental knowledge can be demonstrated through environmental behavior which is a component of cognitive and conative used as the basis for the formation of environmental awareness. This means that individuals who have environmental knowledge will have the ability to overcome environmental issues by creating green products and these products are used as a form of solving environmental problems shown through behavior. In accordance with the study conducted by Karatas and Gürbüz, 2016, which stated that if there were cases of damage to the natural environment, it is necessary to provide environmental knowledge, in order to form public awareness in overcoming environmental problems. Furthermore, environmental knowledge is the basis for generating positive environmental attitudes (Zsóka *et al.*, 2013). Another study also explained that environmental knowledge influences attitudes towards the natural environment (Tamar *et al.*, 2020; Liu *et al.*, 2020). Therefore, environmental knowledge becomes the main predictor to influence environmental attitudes. With the needs and desires

of consumers for green products, there is an awareness of managers to use environmentally friendly marketing strategies in order to get attractiveness from consumers on the products. Green products can be produced if there is environmental awareness from managers. This is in line with the finding by Kautish and Sharma, 2020, which revealed that people with a greater environmental awareness will have a big effort to prevent environmental exploitation and contribute to environmental sustainability, thus leading them to use green products. Furthermore, environmental awareness and environmental knowledge can lead to positive changes in environmental attitudes (Law *et al.*, 2017). People with environmental knowledge and awareness can more easily present an environmentally friendly attitude (Chen *et al.*, 2015; Law *et al.*, 2017). The more people have a good attitude and make positive choices for the environment, the more likely they are to use green products (Leroux and Pupion, 2018). Sreen *et al.*, 2020; Suki, 2016 have established a significant relationship between environmental attitudes towards green products. In addition to having a direct influence, environmental awareness also has an indirect influence (mediation). This is supported by studies conducted by Karatas and Gürbüz, 2016; Osman *et al.*, 2016, which revealed that environmental awareness mediates the effect of environmental knowledge on environmentally friendly attitudes and green products. However, this kind of mediation has not been studied from a manager's perspective. Then an environmentally friendly attitude fully mediates the relationship between environmental knowledge and green products, which means that high environmental knowledge causes a positive attitude to the environment which will have an effect on green products (Binti Aman, 2011). Furthermore, environmentally friendly attitudes are also influenced by environmental awareness because environmental awareness has several components, such as, environmental knowledge, environmental values, and environmental attitudes (Fu *et al.*, 2017; Abdul-Wahab and Abdo, 2010). Therefore, an environmentally friendly attitude is a part of environmental awareness. People with an awareness of environmental protection will be indicated by a favorable attitude towards green products. Based on the description, the conceptual framework can be

### Environmental green product

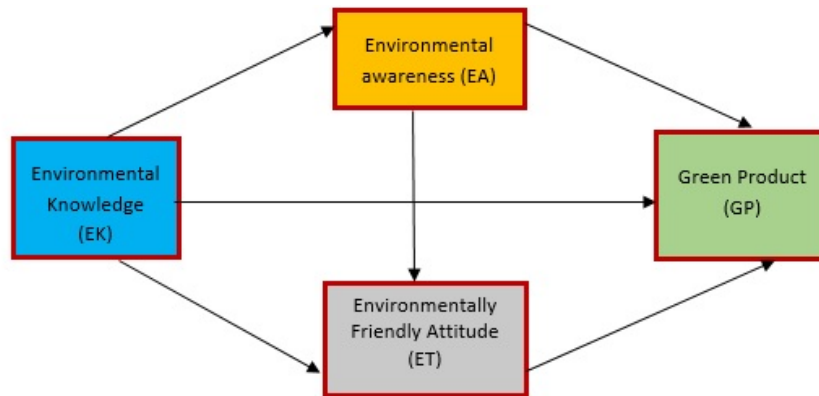


Fig. 1: The conceptual framework of research work

Table 1: Measurement method (questionnaire and scaling)

Variable	Indicators	Industry type	Source
Environmental knowledge	1-6	Manufacture	<a href="#">Fawehinmi et al., 2020</a>
Environmental awareness	1-8	Manufacture	<a href="#">Cao and Chen, 2019</a>
Environmentally friendly attitude	1-8	Manufacture	<a href="#">Safari et al., 2018</a> ; <a href="#">Adrita and Mohiuddin, 2020</a>
Green product	1-7	Manufacture	<a href="#">Kong et al., 2016</a>

proposed as shown in Fig. 1. The aim of the current study is to examine the effect of environmental knowledge on green products affected by knowledge, awareness, and environmentally friendly attitudes, thus providing important insights for business stakeholder in facilitating the development of green products. This research has been conducted in West Sumatera, Indonesia in 2021.

## MATERIALS AND METHODS

The population of this study were managers of manufacturing companies in West Sumatera, Indonesia. The sample were 216 managers who were selected using purposive sampling technique. This study used partial-least-squares structural-equation-modeling (PLS-SEM) with the help of the Smart PLS statistical tool. The reason for using PLS-SEM is that this research is a predictive study and the additional characters in this study such as environmental awareness and environmentally friendly attitudes become mediators between environmental knowledge and green products. In addition, PLS-SEM is widely used because of its robustness by providing evidence of higher reliability and validity even in small sample studies ([Henseler et al., 2009](#)).

### Measurement (questionnaire and scaling)

The questionnaire was developed based on several previous studies. The questionnaire was answered using a Likert scale ranging from strongly disagree with a score of 1 to strongly agree with a score of 5 in measuring each construct. The measurement of environmental knowledge was adopted from [Fawehinmi et al., 2020](#), while the measurement of environmental awareness was adopted from [Cao and Chen, 2019](#). Measurement of environmentally friendly attitude constructs was based on [Safari et al., 2018](#); [Adrita and Mohiuddin, 2020](#) and green product measurements were adopted from [Kong et al., 2016](#). It can be seen in Table 1.

## RESULTS AND DISCUSSIONS

### Characteristic of respondents

The results showed that the most male respondents participated with a percentage of 53% while the rest were female respondents with a percentage of 47%. Meanwhile, when viewed from the age of the respondents, the age range of 40-45 years was the most dominant with the highest percentage of 65%. Furthermore, 56% of the respondents held a master's degree from a state university, 60% of respondents

worked as a production manager, and 70% of the respondents have worked for 15 years.

#### Measurement of model assesment

Smart PLS 3.0 was used to analyze the data (Ringle *et al.*, 2015). PLS-SEM uses two important stages, the measurement model and the structural model (Anderson and Gerbing, 1988; Henseler *et al.*, 2009). The analysis of the measurement model was used to determine the validity and the reliability of the data. The analysis of the measurement model consists

of; 1) loading factor for each question item from each construct, 2) internal composite reliability, 3) average variance extracted (AVE) and 4) discriminant validity. The above models were used to evaluate the measurement model whose construct is reflective. In this study, all indicators were measured as reflective constructs. The measurement model had been analyzed based on partial-least-squares structural-equation-modeling, with the help of smart PLS 3.0 (Ringle *et al.*, 2015). Table 2 showed the results of the assessed measurement models. Table 2 showed

Table 2: Assesment result of measurement model

Construct	Indicator	Loading factor	Composite Reliability	AVE
EK	Know environmental issues	0.824	0.900	0.750
	Have good knowledge of environmental issues	0.874		
	Protect the environment from pollution	0.899		
EA	Provide a healthy work environment	0.812	0.929	0.687
	More concerned with the company environment	0.825		
	Designe an eco-friendly enterprise system	0.841		
	All members of the organization must design an environmentally friendly company system	0.861		
	Organization members are more concerned with the company's environment	0.853		
	Company reputation as an environmentally conscious organization	0.779		
ET	Working in an eco-friendly company is a positive	0.911	0.970	0.801
	Good image about implementing environmentally friendly behavior	0.880		
	Caring about the environmental consequences of behavior	0.900		
	Have strong feelings about eco-friendly behavior	0.885		
	Involvement in environmental activities will save the environment for future generations	0.921		
	It is important to promote eco-friendly living	0.891		
	More action is needed on environmental protection	0.880		
	It is important to increase environmental awareness	0.890		
GP	Produce quality products	0.844	0.886	0.722
	The resulting product is beneficial to the environment	0.881		
	Use product packaging materials that are safe for the environment	0.823		

Table 3: Discriminant validity (HTMT ratio)

Constructs	GP	EA	EK	ET
GP				
EA	0.770			
EK	0.617	0.797		
ET	0.072	0.068	0.114	

the loading factor exceeding the recommended value of 0.7 (Hair et al., 2013). Furthermore, the results of composite reliability were higher than the recommended value of 0.6 and the AVE values were higher than the minimum criterion of 0.5 (Fornell and Larcker, 1981). Thus, the model built was categorized as good so that it provided adequate support. Based on the measurement validation analysis, all HTMT (heterotrait-monotrait) ratios were lower than the maximum threshold of 0.85 suggested by Henseler et al., 2015, as shown in Table 3. The analysis showed sufficient evidence for the discriminant validity of all constructs.

From Tables 2 and 3, it can be seen that the data of results met the requirements of the measurement model. Followed by structural model analysis, the point is to test the tested hypotheses through significance, path coefficients, and t-statistics as well as estimate the mediation model.

#### Structural model assesment

In accordance with the purpose of this study as stated in Fig. 1, to assess the direct effect and indirect

effect (mediation), structural model analysis was used. This study had six direct hypotheses. Three hypotheses were accepted (H1; H2; H4) because the p-value was less than 0.05 but (H3; H5; H6) was rejected because the p-value is more than 0.05 as shown in Fig. 2 and Table 4.

Then, to test the mediating effect, the PLS-SEM bootstrap technique was applied (Hair et al., 2010), which can be done by re-sampling five hundred samples (Ringle et al., 2015). As revealed by Chin et al., 2003, PLS can provide a more accurate estimate of the mediating effect by taking into account errors that weaken the predicted relationship and increase theory validation (Helm et al., 2010). Table 5 showed the results of the mediation analysis. The mediating effect was only found in H7a because the p values were smaller than 0.05 but the hypothesis of H7b; H8a; H8b were rejected because the p values were greater than 0.05 which can be seen in Fig. 2. Therefore, environmental awareness and environmentally friendly attitudes did not mediate the relationship between environmental knowledge of green products in manufacturing companies in

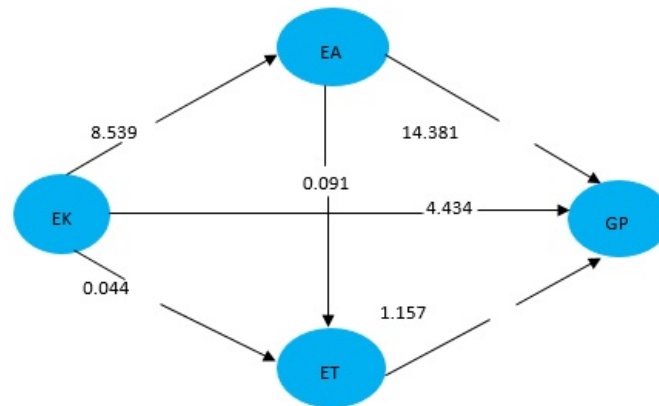


Fig. 2: Direct effects, structural model assessment. It mainly showed the t-value and path coefficient for accepting or rejecting the hypothesis

Table 4: Structural model assesment (direct effect result and decision)

Hypothesis	Relationship	Original sample (O)	Average sample (M)	SD	T Statistic ( O/S.D.)	P- values	Decision
H1	EK-> GP	0.298	0.295	0.067	4.434	0.000	Accepted
H2	EK -> EA	0.694	0.699	0.048	14.381	0.000	Accepted
H3	EK -> ET	0.117	0.110	0.101	1.157	0.248	Rejected
H4	EA -> GP	0.543	0.547	0.064	8.539	0.000	Accepted
H5	EA -> ET	0.010	0.010	0.108	0.091	0.927	Rejected
H6	ET -> GP	0.002	0.004	0.044	0.044	0.965	Rejected

West Sumatera, Indonesia.

Table 6 showed the value of R Square ( $R^2$ ). Testing the value of  $R^2$  aimed to see how the independent variable is able to describe the dependent variable. In this study, the contribution given by environmental knowledge to environmental awareness was 48.2%, then the contribution given by environmental knowledge and environmental awareness to environmentally friendly attitudes was 1.2%. Finally, the contribution made by environmental knowledge, environmental awareness, and environmentally friendly attitudes towards green products was 60.7%.

In addition, the effect size ( $F^2$ ) for each path model was calculated. Table 7 showed the output of the effect size ( $F^2$ ). The value of  $F^2$  can be interpreted whether the predictor variable had a weak, moderate or strong influence on the structural level. If the value of  $F^2$  was 0.02 then it had a weak effect, while 0.15 had a moderate effect and a value of 0.35 had a strong influence (Hair *et al.*, 2010). Based on Table 7, it indicated that environmental awareness had a strong influence on green products and environmental knowledge had a strong influence on environmental awareness.

#### Direct effect

Environmental knowledge had a significant direct impact on green products. These findings were in line with Li *et al.*, 2019. Respondents' perception of protecting the environment from pollution was very high which can be seen in Table 2, meaning that manufacturing managers will use some of their ecological knowledge in the production process thus contributing to environmental improvement such as protecting the environment from pollution in various actions. Similarly, environmental knowledge had a significant direct impact on environmental awareness. The results of this study were in accordance with Zsóka *et al.*, 2013; Zhan *et al.*, 2018; Karatas and Gürbüz, 2016. To increase environmental awareness, the company must pay attention to the flow of knowledge and environmental learning. Furthermore, environmental awareness had a significant direct impact on green products. These findings supported research conducted by Kautish and Sharma, 2020, which stated that environmental awareness significantly affected green products from the consumer's point of view. From the producer side, it also explained that the manager's perception

Table 5: Structural model assesment (indirect effect result and decision)

Hypothesis	Relationship	Original Sample (O)	Average sample (M)	S.D.	T Statistik ( O/S.D.)	P- values	Decision
H7a	EK -> EA -> GP	0.377	0.379	0.052	7.221	0.000	Accepted
H7b	EK -> EA -> ET	0.007	0.004	0.079	0.086	0.931	Rejected
H8a	EK -> ET -> GP	0.000	0.000	0.007	0.033	0.974	Rejected
H8b	EA -> ET -> GP	0.000	0.000	0.004	0.004	0.997	Rejected

Table 6: R square ( $R^2$ )

Construct	R square	Adjusted R square
GP	0.607	0.601
EA	0.482	0.479
ET	0.012	0.002

Table 7: Effect size ( $F^2$ )

R-squared	Fsquared	Effect size $F^2$
EK → GP	0.116	Weak
EA → GP	0.389	Strong
ET → GP	0.000	Weak
EK → EA	0.930	Strong
EK → ET	0.007	Weak
EA → ET	0.000	Weak

of environmental awareness was very high which can be seen in Table 2, all company members must design environmentally friendly company products, meaning that managers' awareness of designing green products was very high, thus, it had an impact on increasing the production of green products. Furthermore, the results of this study indicated that environmental knowledge had no significant effect on environmentally friendly attitudes. It indicated that the ecological knowledge did not lead to attitudes which can be beneficial to the environment. These findings were supported by Paço and Lavrador, 2017; who found that despite a high level of environmental knowledge, individuals did not show positive environmental attitudes. This finding contrasted with empirical studies conducted by Tamar et al., 2020; Liu et al., 2020 which showed that environmental knowledge had a significant effect on environmentally friendly attitudes. The explanation of this case is that environmental knowledge results from the learning process does not lead managers to an understanding of moral values towards the environment. Furthermore, the purpose of obtaining environmental knowledge is not only mastering environmental knowledge but also implementing moral values on the environment, if managers can find moral values for the environment from a subject matter being studied, they can make more efforts and certain sacrifices by showing a positive attitude towards the environment. Thus, environmental knowledge did not affect the attitude of managers in protecting the environment. Then this study found that environmental awareness had an insignificant effect on environmentally friendly attitudes. The thing that causes this research to be insignificant is known from the lack of understanding of the theory of environmental awareness shown in the environmental awareness indicators with item statement number one and two, namely the company had a positive effect on the environment and can make energy savings, where this item is excluded in the research model because the invalidity of the statement item, thus, the manager's awareness of the environment is weak. Therefore, environmental awareness did not have an important role in being environmentally friendly. The results of this study were in accordance with study by Mustikaningrum, 2018 which stated that environmental awareness had a negative and insignificant effect on environmentally friendly attitudes but contrasted with research conducted by Chen et al., 2015; Law et

al., 2017, who found that environmental awareness was an important determinant of environmental issues, attitudes, and responsibilities. Furthermore, the finding showed that environmentally friendly attitudes had no significant effect on green products. The results of this study implied that there was a little availability of green products because the synergy of the presence of environmentally friendly companies in building positive attitudes related to the environment is relatively low in developing countries, especially in West Sumatera, Indonesia, compared to developed industrial countries. The results of this study were not in line with research conducted by Sreen et al., 2020; Suki, 2016, which explained that there was a significant relationship between favorable attitudes towards green products.

#### *Indirect effect (mediating effect)*

This finding also explained that environmental awareness mediated the relationship between environmental knowledge and green products (H7a). It indicated that environmental knowledge must be implemented to form awareness of the importance of environmental protection which can encourage company managers to increase the production of green products. This was confirmed by Karatas and Gürbüz, 2016; Osman et al., 2016, who explained that environmental knowledge had a significant positive effect on green products through environmental awareness. Furthermore, environmental awareness did not mediate the relationship between environmental knowledge and environmentally friendly attitudes (H7b), environmentally friendly attitudes did not mediate the relationship between environmental knowledge on green products (H8a), and environmentally friendly attitudes did not mediate the relationship between environmental awareness and green products (H8b). The results of this study were in line with research carried out by Hansla et al., 2008, which stated that an environmentally friendly attitude was not a mediator variable. In short, environmental awareness was an important mediation in explaining the relationship between environmental knowledge and green product based on company managers.

#### **CONCLUSION**

Managers' awareness of the environment must be realized by sharing knowledge about the importance of protecting the environment because this will affect

the production of green products. Environmental awareness had an important role in explaining the relationship between environmental knowledge and green products from the perspective of manufacturing managers. Thus, the effort to increase the production of green products was the building of manager awareness by sharing knowledge and learning about the importance of protecting the environment. From these findings, a number of managerial implications can be suggested as manufacturing companies must increase the production of green products properly, thus, they are not harmful for human health or environment. In the future, the majority of companies will go green, so manufacturing companies must follow this trend by making a "green manufacturing" where the products must be subject to the preservation of nature and the environment. Becoming a green manufacturing can be a step to compete with other companies. Therefore, manufacturing businesses must demonstrate their awareness of environmental protection by starting with various environmental actions and services to reduce waste, use of energy and water, and other consumption. Then, it is very important for environmentally friendly manufacturing companies to get an environmental certificate by showing that environmental programs are being implemented, this will certainly help improve the company's image which will ultimately lead to business improvement. More importantly, manufacturing managers must clearly show their true motives for the process of green product, otherwise they will put themselves at risk of being accused of "greenwashing". They are also advised to ensure that every production process must be properly proven and accompanied by evidence. However, this study has some limitations and it is suggested for further research to improve it. First, this research was only conducted in West Sumatera, Indonesia. Therefore, it cannot be generalized to other countries. For further research, it is recommended to expand this research, such as comparing developed countries with developing countries in the process of green products. Second, this research is included in the category of cross sectional research so that it has limitations in explaining the findings. For this reason, it is recommended for further research to conduct research included in the category of longitudinal research. Third, this study only analyzed environmental knowledge, awareness and environmentally friendly attitudes in an effort to increase green product

production. Therefore, further research can add institutional support, managers' intentions and behavior in producing green products to support the findings of this study.

#### **AUTHOR CONTRIBUTIONS**

C. Candrianto conducted the literature review, research design, developed the model, collected and analyzed the data, and prepared the manuscript text. H. Aimon arranged and designed the research. S.U. Sentosa analyzed and interpreted the data.

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#### **CONFLICT OF INTEREST**

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

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## ABBREVIATIONS

%	Percent
—→	Arrow symbol
AM	Average sample
AVE	Average variance extracted
EA	Environmental awareness
EK	Environmental knowledge
ET	Environmental attitude
<i>et al.</i>	Et alia
FE	Fixed effect
Fig.	Figure
GP	Green product
H1	Hypothesis 1
H2	Hypothesis 2
H3	Hypothesis 3
H4	Hypothesis 4
H5	Hypothesis 5
H6	Hypothesis 6
H7	Hypothesis 7
H8	Hypothesis 8
HTMT	Heterotrait monotrait
<i>i.e.</i>	Id est
O	Original sample
<i>P-value</i>	Probability value
PLS-SEM	Partial least square-structural equation model
<i>R-Square</i> ( $R^2$ )	Determination coefficient
<i>S.D.</i>	Standard deviation
<i>T-statistic</i>	Hypothesis tets statistic
VB-SEM	Variance based-structural equation model

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## ORIGINAL RESEARCH PAPER

# Smart city based on community empowerment, social capital, and public trust in urban areas

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## ABSTRACT

**BACKGROUND AND OBJECTIVES:** Urbanization has been causing many problems for the environment and society. An ineffective and inefficient government also contributes to urban problems by increasing public dissatisfaction and distrust of government. Technological Improvements makes it possible for local governments in Indonesia to implement the concept of "Smart City" as a solution to solve urban problems. This study aims to fill the gap by examining the impact of smart city application on public trust towards the government.

**METHODS:** A primary data collection was conducted in 2021 to profile the citizens' behaviour in terms of smart city application. This study had surveyed four big cities in Indonesia that had built smart city applications well: Jakarta, Bandung, Semarang, and Surabaya. The primary data were analyzed through ordinary least squares regression.

**FINDINGS:** This study founds that the fundamental factors of smart city applications that are statistically significant were on quality, satisfaction, and reliability. These factors had positive and significant impacts on the level of trust in the local government. Based on the regression model, the increase of application quality score by 1 affects the score of trust in the local government, which will rise by 0.440 (Jakarta), 0.269 (Bandung), and 0.245 (Semarang), and 0.212 (Surabaya). The increase in application satisfaction score by 1 affects the score of trust in local government, which will rise by 0.193 (Jakarta), 0.431 (Bandung), 0.07 (Semarang), and 0.186 (Surabaya). Also, an increase in application reliability score by 1 affects a rise in trust in local government by 0.187 (Jakarta), 0.204 (Bandung), 0.137 (Semarang), and 0.192 (Surabaya).

**CONCLUSION:** Smart city applications can shape public trust by increasing the application's quality, satisfaction, reliability and community empowerment. However, it should be noted that the number of community which uses smart city application is still low. Therefore, It is necessary to encourage a culture of using those applications to help build citizens' trust in the government and improve urban quality.

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## INTRODUCTION

Urbanization is accelerating and it is putting more pressure on the environment and society. Developments that are not well planned also adds to this burden. Such Problems arise due to population growth, economic changes, pandemics, corruption, and many other factors. Ineffective and inefficient government solutions exacerbate public dissatisfaction and distrust of government. It threatens the government, obstructs government operations, and even threatens the rule of law. According to data on public trust in Indonesia, public trust in the government has declined. One of the reasons for the drop in confidence is the government's performance in dealing with the pandemic. The decline in public trust in the government during the COVID-19 pandemic is discussed by [Rachmawati et al. \(2021\)](#). Reduced trust is associated with a lack of preparedness and ineffective management, resulting in an increase of economic losses and community suffering. The corruption level, which contributes to the trust decline, is also further caused by the economic crisis ([Schumacher, 2013](#)). The erosion of trust poses a risk to government operations and even disrupts the regional economy. A lack of trust can harm the rule of law. In response to this, the government has begun to turn to technology that can solve urban problems. Nowadays, technology has become an integral part of human life that cannot be separated from it. Technology is integrated into transportation, traffic monitoring applications, education, and various other areas. Technology is constantly evolving. As society enters the fourth industrial revolution, technological advancements focus on digital technology. People are unavoidably entering an era where all activities are being conducted digitally. The Internet of Things (IoT) or artificial intelligence (AI) are some of the terms used to describe this era ([Kaginalkar et al., 2021](#); [Zhang et al., 2017](#)). Automation occurs due to digital transformation in industrial application systems or government activities. Because of this, various applications aimed to aid urban development have been launched in conjunction with smartphones. Collaborating with the community is one of strategies that can help raise participation awareness. Today, Smartphones are not considered as a luxury item. It is affordable to almost everyone, making it easier for people to adopt and use the available applications. Smartphone support makes it easier to use such

applications from the government to the community because it can reach almost everyone. Several regions have attempted the transition to a smart city, but the road to such transition is not easy. Nevertheless, the public is interested in the smart city application since it provides several benefits, including convenience and sustainability. The community is aware of the importance of participating in the upkeep of public spaces ([Jeannot, 2018](#)). Some applications provide waste sorting, public transportation complaint hub, and more. Smart cities have been widely adopted in Indonesian cities such as Jakarta, Surabaya, Bandung, Semarang, and others. In the case of Jakarta, the city have created a smart city application named *Jakarta Kini* (JAKI). Other cities such as Bandung has a smart city application named *Bandung Sadayana Smart City*, Semarang has a smart city application named *Semarang Smart Transportation City*, and Surabaya has a smart city application named *Wadah Usulan dan Keluhan* (E-Wadul). The government uses smart cities to ensure security, comfort, and public order. Many studies have been conducted on the community's adoption of smart city applications ([Bélanger and Carter, 2008](#); [Zhang et al., 2018](#)). [Sanawiri and Agusti \(2019\)](#) had tried to compare and contrast smart city applications in terms of value proposition and smart city framework. However, previous researches on smart cities to solve public trust issue shows that cyber security and data transparency have been an obstacle in increasing public trust on smart cities ([Braun et al., 2018](#); [Ma, 2021](#)). According to previous research, there are a few links between smart city applications and government trust. In addition, there are other factors outside of cyber security and data transparency issues that impact public trust on smart cities. This study attempts to fill this gap by examining the impact of smart city applications on public trust in government, which is examined by comparing several regions. However, whether smart city applications reflect a more intense correlation between government and society and whether this correlation has implications for citizens' trust in government remains to be seen. This study investigated the correlation between application quality, user satisfaction, reliability, and government trust. With the variety of smart city applications offered by local governments base on public trust and community empowerment. This study took samples in four different cities in Indonesia to compare

application usage in these cities using comparative analysis.

#### *Smart city application adoption and social capital*

A smart city is a concept that is quite popular in various parts of the world. It is common to incorporate science, technology, and the Internet of Things (Zhang *et al.*, 2017) into human activities. This platform connects online database services that can be used with available application. Technology is merely a government-provided means of interaction (Razak *et al.*, 2021). The government is the authority that regulates the governance, but community initiatives are central to the governance of a smart city (Paskaleva *et al.*, 2017). According to Jeannot (2018), e-government focuses more on administrative aspects, work services, and information on rule enforcement. A smart city, on the other hand, is primarily for administrators. One aspect of a smart city is e-government. The concept of a smart city is based on Information and Communication Technologies (ICT), which can be used to entice the public to participate in smart city services or applications. Smart city goals have shifted away from infrastructure development to service providers (Kim, 2022). Smart city applications that offer digitization services and develop applications with technology support provide opportunities for increasing the communication between the government and the community (Sanawiri and Agusti, 2019). Smart city applications offer better environmental quality to improve people's welfare sustainably (Goldfinch *et al.*, 2009). Digital platforms have facilitated transparency and community participatory mechanisms (Criado and Gil-Garcia, 2019). However, how is willing is the society in adopting the application? Application adoption is based on the level of confidence in the government (Alzahrani *et al.*, 2017). Lack of trust is a barrier to adopting smart city applications (Beldad *et al.*, 2012). Smart city applications vary widely in several regions, depending on the needs and goals of the local government. The government, in this case, cooperates with the private sector to form a platform to attract public participation. Public and private collaboration can demonstrate flexibility in responding to urban needs (Kim, 2022). Zheng and Schachter (2017) discuss the willingness of people to participate in applications. The benefits that

users' get is the most significant driving variable. The main difficulty in adopting applications is not a technical problem but rather a social one (Jeannot, 2018). The term "trust" refers to how people feel about the government's performance. Trust is the primary concern in democratic government and public administration (Tolbert and Mossberger, 2006). Technology, government agencies, citizen aspects, and risk factors impact trust (Alzahrani *et al.*, 2017). The public's perception of the government's capacity and integration in the delivery of public services shape trust. Process-based trust and institution-based trust are two types of trust. Repeated interactions between the government and the community build process-based trust (Alamsyah *et al.*, 2016). The interaction is shaped by the government's previous experience and reputation in processing program performance (Beldad *et al.*, 2012) that the community has felt. Lack of trust in government can reduce government legitimacy (Tolbert and Mossberger, 2006). The level of public trust can be seen in their willingness to participate in politics (Goldfinch *et al.*, 2009). Trust is one of the individual social capital variables that have important impact on how citizen to cooperate with government through e-participation (Choi and Song, 2020). This study on investigating public trust also have implication on social capital because Srirama *et al.* (2020) explains that on social capital there are 2 dimensions which trust is a part of, consisting of relational dimension and structural dimension. Trust is part of relational dimension on social capital theory. Socio Citizenry theory describes government-citizen interactions through social media (Aladwani and Dwivedi, 2018). There are three primary constructs in Socio Citizenry: the anticipation of quality, the configuration of trust, and agreed adaptation. Smart city applications have been shown in previous studies to increase citizen interaction and form new public perceptions or values (Lim *et al.*, 2021). The current study study aims to increase public trust in the government, resulting in better regional development. The problem of public distrust is not a minor one, and a solution must be found as soon as possible. This study was carried out in four big cities in Java Island, Jakarta, Bandung, Semarang, and Surabaya of Indonesia was conducted face-to-face with strict health protocols in 2021.

## MATERIALS AND METHODS

### *Data, assumptions and limitations*

The data used in this study were a primary data sample obtained from a google form online survey. The survey data used in this study were obtained from 4 different metropolitan cities in Java Island (Indonesia): Jakarta, Bandung, Semarang, and Surabaya. From the primary data collection, the survey gathered 816 respondents, consisting of 209 respondents from Jakarta, 210 respondents from Bandung, 198 respondents from Semarang, and 199 respondents from Surabaya. The survey itself consisted 8 sections, where each section contained up to 7 questions. The sections asked on the survey were as follows:

- Part 1: Respondents' obedience to local guidance and instructions
- Part 2: Respondents' opinions, tips, and recommendations on a local smart city application
- Part 3: Self-confidence in problem-solving ability
- Part 4: Trust aspects of local government
- Part 5: The existence of helpful neighbourhoods, friends and relatives
- Part 6: Smart city application quality of service
- Part 7: Respondents' impressions, perceptions, and engagement with local smart city application
- Part 8: Respondents' satisfaction on local smart city application.

Multiple sections, as mentioned above, were used to profile respondents' behaviour, perception, engagement, and satisfaction on the smart city application in their respective cities. In this study, the results of all questions were not included. Only relevant questions (variables) used in the regression model would be shown in summary statistics. The sampling method used in this survey was random purposive sampling. Random individuals were taken from intended cities with well-managed smart city applications that can be installed in common smartphones in most used operating systems (Android and iOS). Individuals recorded in this survey were independent of each other and came from different households. Only citizens who had smart city application installed on their smartphones were recorded in this survey. Smart city applications that the respondents had scored were different based on the city they lived in: the applications issued by the city government of Jakarta, Bandung, Semarang, and Surabaya.

### *Regression model*

This study employed an ordinary least squares (OLS) regression model to estimate the impact of the variable of interests and control variables to score trust in local governments. The score of trust in local government was measured from respondents' answer on how well they could trust the local government in managing the city and solving citizens' daily issues, ranging from 1 to 6. Hence, citizens' trust in their respective local governments varied from 1 to 6. In this study, the factors (primarily related to smart city applications) which affected the trust score was analyzed. The variables of interest were the smart city application quality, citizens' (respondents) satisfaction on the smart city application, and the smart city application reliability score. The control variables used in this study were respondents' age, years of schooling (proxy of education level), and gender. In this study, both the dependent variable (score of trust in local government) and the variable of interests (score of smart city application quality, citizens' satisfaction on the smart city application, and the score of smart city application reliability) had the same magnitudes, where respondents rated those aspects from 1 to 6. Hence, this study focused on respondents' level of trust in their respective local governments, with their general perceptions of smart city application as the main factor affecting their trust in local government. The assumption that was used on the regression model is the linearity. The regression model is shown in Eq. 1.

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \varepsilon \quad (1)$$

Where;

$Y$  = Score of trust to local government

$\beta_0$  = Intercept

$\beta_1$  to  $\beta_6$  = Coefficient parameter of independent variables

$X_1$  = Score of smart city application quality

$X_2$  = Score of smart city's satisfaction from citizens

$X_3$  = Score of smart city application reliability

$X_4$  = Age (in years)

$X_5$  = Years of schooling (in years)

$X_6$  = Dummy variable of gender

$\varepsilon$  = Error terms

This study analyzed how the variable of interest affected the dependent variable comparatively in

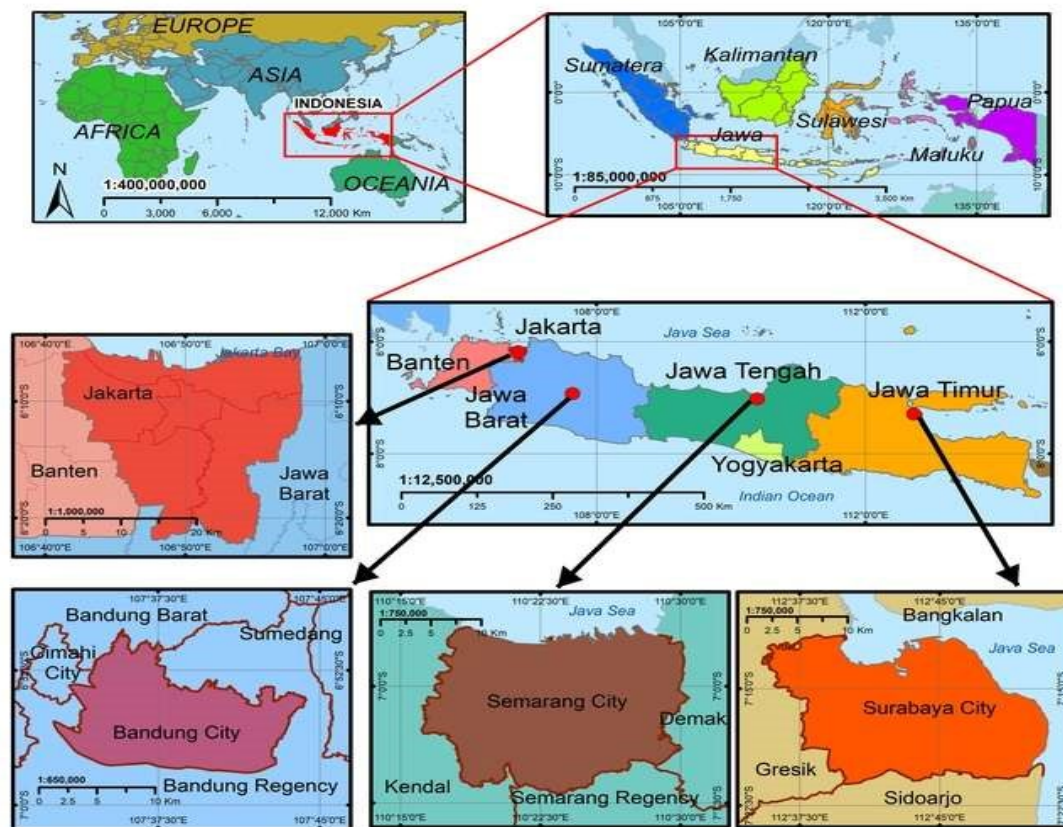


Fig 1: Geographical Location of the study area in the four different metropolitan cities in Java Island, Indonesia; 1- Jakarta, 2- Bandung, 3- Semarang, 4- Surabaya in Indonesia

each observed city. Hence, the same regression had been run separately on respondents from each city to achieve a comparative analysis. The result was grouped based on cities. In the following paragraphs and analysis, the word 'app' refers to a smart city application operated by the local government in observed cities. This study examined how citizens' trust in local government was formed in the context of the smart city and digital well-being that the local government had created.

## RESULTS AND DISCUSSION

### Summary statistics

Before this study goes to the regression analysis, the summary statistics are presented to show the sample profile of this study. The summary statistics data is shown in Table 1.

The purpose of Table 1 as descriptive statistic is

to summarize the characteristics of data based on the variable that were used in this study. As seen in the table above, citizen samples from Semarang have the most average trust score for the local government (5) compared to other cities. This high level of trust in Semarang citizens was also followed by the smart city application quality score (4.92) and the highest application satisfaction level (4.88) compared to the others. However, those high trust and quality was not followed by the application reliability since Semarang has the lowest average score of application reliability (4.31). On the demographical factor, the average age of respondents in Jakarta is the youngest (26.09) compared to the other cities. In addition, in Jakarta, the respondents have the highest average years of schooling (13.72) compared to other cities. Overall, the number of male respondents is more than the number of female respondents, except in Surabaya city.

Table 1: Summary statistics

Variables	Jakarta	Bandung	Semarang	Surabaya	Total
The score of the local government trust					
Mean	4.95	4.89	5.00	4.97	4.95
S.D.	1.19	1.13	0.51	0.73	0.94
Frequency	209	210	198	199	816
The score of smart city application quality					
Mean	4.83	4.82	4.92	4.65	4.81
S.D.	1.15	1.17	0.59	0.81	0.97
Frequency	209	210	198	199	816
The score of smart city application satisfaction					
Mean	4.83	4.85	4.88	4.82	4.85
S.D.	1.09	1.07	0.66	0.77	0.92
Frequency	209	210	198	199	816
The score of smart city application reliability					
Mean	4.67	4.84	4.31	4.80	4.66
S.D.	1.15	1.06	0.83	0.79	0.99
Frequency	209	210	198	199	816
Age					
Mean	26.09	29.95	30.74	31.46	29.52
S.D.	6.82	10.72	9.03	8.96	9.21
Frequency	209	210	198	199	816
Years of schooling					
Mean	13.72	12.60	12.48	13.62	13.11
S.D.	2.47	2.03	2.44	2.26	2.37
Frequency	209	210	198	199	816
Sex/gender					
Female	71	83	75	103	332
Male	138	127	123	96	484
Total	209	210	198	199	816

### Regression Results

In this study, the regression was run separately on respondents from 4 sampled cities (Table 2). This comparative analysis analyzed how the variable of interests and control variable affected the dependent variable in each case of the city as well as the characteristics which indicates how it might differ from each other.

According to the regression result in Table 2, it is shown that application quality has a significant impact on the score of trust in the local government. As the results showed, the coefficient parameter of the application quality is statistically significant at a 99% confidence level, with different magnitudes in each city. Table 2 is used to indicate the main findings from each variables and each cases that are statistically significant. Comparatively, Jakarta has the highest coefficient parameter, meaning that citizens in Jakarta will trust the local government more as the quality of smart city application rises. Statistically,

when the application quality score rises by 1, the score of trust in the local government will rise by 0.440 (Jakarta), 0.269 (Bandung), 0.245 (Semarang), and 0.212 (Surabaya). To deepen the understanding of how smart city application quality affects the trust score of local government, this study also conducted a graphical simulation based on the regression model above. In Fig. 2, it is shown that citizens of Jakarta and Bandung create a higher slope of the curve (steeper), meaning that an increase in application quality by one will result in a higher increase of trust compared with two other cities (Semarang and Surabaya). The slope of the curve of citizens in Semarang and Surabaya is relatively more declivous than in Jakarta and Bandung, meaning that the increase of application quality by one will result in a lower increase of trust in local government.

The quality of government social media affects public trust, which in turn will affect the level of adaptation of social media (Aladwani and Dwivedi,

Table 2: Regression results

Variables	Jakarta	Bandung	Semarang	Surabaya	Total
The score of the local government trust					
Mean	4.95	4.89	5.00	4.97	4.95
S.D.	1.19	1.13	0.51	0.73	0.94
Frequency	209	210	198	199	816
The score of smart city application quality					
Mean	4.83	4.82	4.92	4.65	4.81
S.D.	1.15	1.17	0.59	0.81	0.97
Frequency	209	210	198	199	816
The score of smart city application satisfaction					
Mean	4.83	4.85	4.88	4.82	4.85
S.D.	1.09	1.07	0.66	0.77	0.92
Frequency	209	210	198	199	816
The score of smart city application reliability					
Mean	4.67	4.84	4.31	4.80	4.66
S.D.	1.15	1.06	0.83	0.79	0.99
Frequency	209	210	198	199	816
Age					
Mean	26.09	29.95	30.74	31.46	29.52
S.D.	6.82	10.72	9.03	8.96	9.21
Frequency	209	210	198	199	816
Years of schooling					
Mean	13.72	12.60	12.48	13.62	13.11
S.D.	2.47	2.03	2.44	2.26	2.37
Frequency	209	210	198	199	816
Sex/gender					
Female	71	83	75	103	332
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Total	209	210	198	199	816

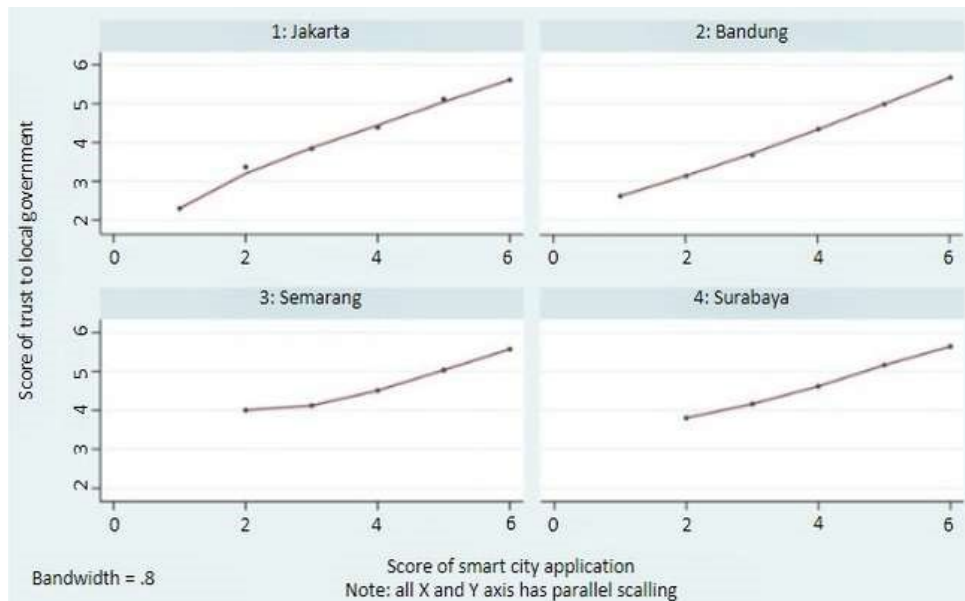


Fig. 2: Impact of application quality on citizens' trust in local government

2018). Smart management and services are linked to application quality (Razak *et al.*, 2021). Application management and solving urban problems are examples of the government's smart management. Local governments have improved service quality by providing efficiency, transparency, and excellence through smart city applications (Pimenta *et al.*, 2018). The government provides good application services to increase community participation while achieving government goals for improving urban sustainability (Allen *et al.*, 2020). Previous research on public trust also shows the result that quality is a significant factor toward public trust (Nulhusna *et al.*, 2017; Brous *et al.*, 2020). However, Nulhusna *et al.* (2017) shows the research that service quality have no significant relationship towards trust, but rather, the informational quality is have significant relationship to trust. Therefore, to improve the public trust, government should improve the information quality.

To improve people's satisfaction, the government continues to improve the applications' quality. The government has tried to improve the application's features and capabilities. Improvements to the application's quality are still being made to meet the goals that must be achieved by building application resiliency in the face of unforeseen events. Cosgrave

*et al.* (2014) emphasize the importance of increasing resilience for application sustainability. Growing the number of innovations available can help ensure long-term viability. The second variable of interest is application satisfaction. According to the regression result, application satisfaction plays an essential role in determining trust towards local government. However, this is not the case in every cities, but rather, only some of the cities is statistically significant. In all cities, application satisfaction positively impacts the citizens' trust, meaning that an increase in application satisfaction will also increase citizens' trust in local government. The coefficient parameter of application satisfaction in Jakarta is significant at a 95% confidence level, while in Bandung and Surabaya is significant at a 99% confidence level. Only coefficient parameters in the case of Semarang are not statistically significant. Statistically, when the application satisfaction score rises by 1, the score of trust in the local government will rise by 0.193 (Jakarta), 0.431 (Bandung), 0.07 (Semarang), and 0.186 (Surabaya). A simulation also has been conducted to see how application satisfaction affects the score of trust based on the regression model. That simulation is shown in Fig. 3. Graphically, most cities have a bending curve, meaning that trust in local government will not increase until application

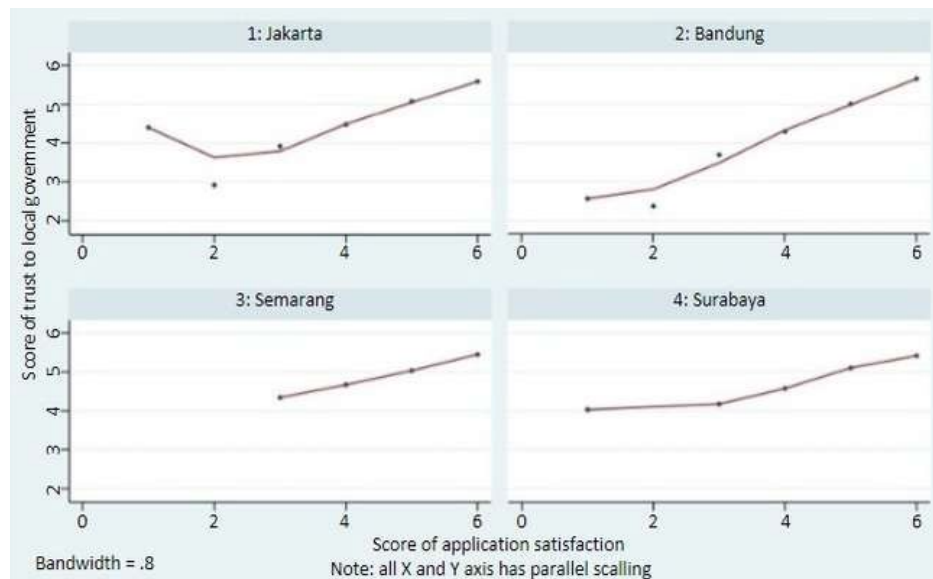


Fig. 3: Impact of application satisfaction on citizens' trust in local government

satisfaction rates reach a certain level. For example, in the case of Jakarta, the trust will rise after the satisfaction level reaches two and above, while other cities have a relatively lower threshold. In the case of Semarang, it does not have a bending curve, meaning that citizens' trust in the government will likely rise linearly as the application satisfaction increases. Satisfaction is essential in determining whether or not an application is successful. User satisfaction is a criterion for evaluating the level of service provided (Zheng and Schachter, 2017). Operational effectiveness is the most substantial variable that has a direct impact on the level of user satisfaction, according to Santa *et al.* (2019). Meanwhile, system and service quality perceptions have a more negligible direct impact than information quality. According to Zhu and Alamsyah (2022), community satisfaction is linked to community empowerment. The community believes that the government has increased community satisfaction by making government efforts transparent. Transparency and satisfaction on the government's performance can also help build public trust (Soonhee and Jooho, 2012). People who have used the application have a higher sense of security in Jakarta, according to Allen *et al.* (2020). The government will follow the reporting perception immediately to provide a

sense of safety and security. The level of community satisfaction in Jakarta has risen due to problems being solved through community reporting. Pérez-Morote *et al.* (2020) discuss the e-participation index (EPI), which affects the satisfaction of smart city services. The more participants use the application, the more satisfied the users are. The satisfaction felt by users can encourage others to feel the same way, and even individuals can attract non-users of the application to become application users. Nulhusna *et al.* (2017) stated that satisfaction can be as an intermediary between service quality and trust. However, research by Welch *et al.* (2005) shows the result that trust depends heavily on satisfaction because satisfaction is positively related to the trust towards the government. The next variable of interest is the application reliability. According to the regression result, application reliability has a significant and positive impact on the level of trust in the local government. Therefore, the smart city application reliability in solving citizens' daily problems plays an essential role in forming trust in the local government. The coefficient parameter of application reliability is statistically significant, wherein the case of Jakarta, it is significant at 95% confidence level, whereas in Bandung, Semarang, and Surabaya, these are significant at 99% confidence

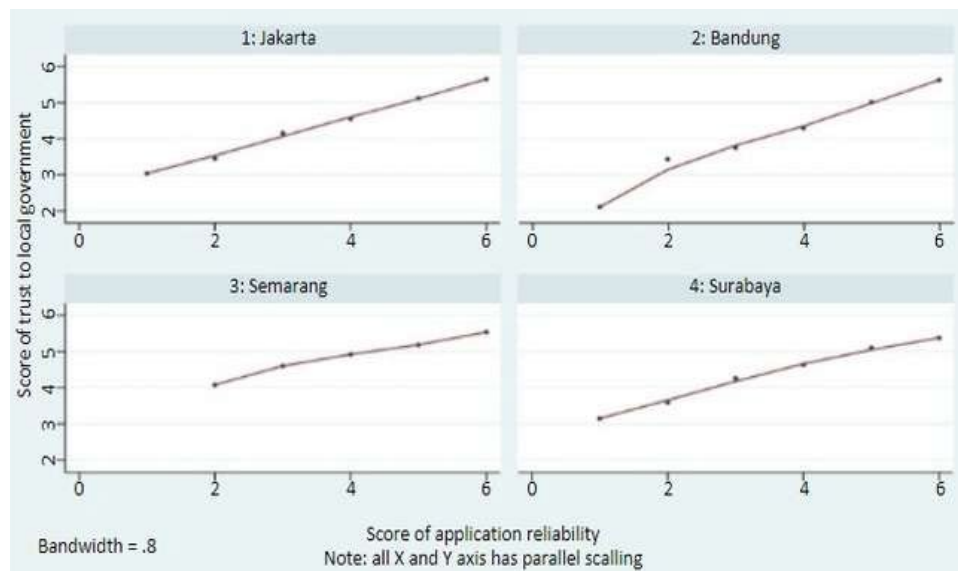


Fig. 4: Impact of application reliability on citizens' trust in local government

level. Statistically, an increase in application reliability by one will be followed by an increase in trust in local government by 0.187 (Jakarta), 0.204 (Bandung), 0.137 (Semarang), and 0.192 (Surabaya). According to the regression result, Bandung has the highest coefficient parameter of application reliability, indicating that the local government has made a notable performance and reliability on their smart city applications, when relatively compared to other observed cities. On the other hand, Semarang has the lowest coefficient parameter compared to the other cities, which indicates that the smart city application of Semarang was not as reliable in comparison to the application of other cities. To deepen the understanding of how application reliability affects the level of trust in local government, the simulation was conducted based on the regression model. In this case, the simulation result is stated on Fig. 4.

According to the result in Fig. 4, all curves form a positive correlation to the trust level, meaning that the application reliability will increase citizens' trust in the local government. In addition, the result shows convergence with the regression table, where the curve slope in the case of Bandung is slightly steeper than the other cities. The steeper curve indicates that an increase in trust level caused by the rise of application reliability in Bandung is higher than the other cities. It serves as a good evidence for the local government of Bandung in managing the smart city ecosystems. The results of this study are supported by Rachmawati et al. (2021), stating that reliability is associated with application optimization. Smart city applications are increasingly offering more exclusive features, covering sectors such as transportation and other problems. Application reliability has solved more complex problems through community participation (Allen et al., 2020). The settlement of damage to urban facilities is reported to be more than routine work such as waste management. Kim (2022) emphasizes the importance of service operation and maintenance over application development. Maintenance is an important step to ensure service continuity. Innovations are offered to the community to attract and increase the application's intensity. Innovation and application development have implications for changing people's behaviour patterns (Cosgrave et al., 2014). The integration of transportation has improved community interaction, transportation efficiency, and urban environment

quality. The application becomes a forum for the community to channel their aspirations, with the application assisting the government in achieving urban performance goals. Because of these forums, when the government takes direct action to increase trust, the effectiveness can be felt right away. Among applications, reliability has been linked through application development. The *Jakarta Kini* (JAKI) application in Jakarta caters to a wide range of requirements and includes numerous features. The application is also improving as a result of such changes. Improved features and innovations can attract more users. The data obtained are then integrated into the application. The public-facing application services have been regarded as high-quality, as evidenced by user satisfaction. The government has been successful in keeping its promises to the public. The initial promises of application adoption were participation freedom, economic benefit, system integration, and environmental benefit. Data maintenance is one factor that affects an application's reliability. The importance of data privatization has made the government secure online data for application users. Data privatization is indispensable for increasing application security (Moustaka et al., 2019). Application data processing should be used so that data is not wasted and is not scattered (Afriani et al., 2021). The application should be optimized for service with no or minimal errors due to the data privatization feature. The fear of leaking personal information in applications discourages adopters (Beldad et al., 2012). Personal data is very vulnerable to misuse. It is crucial to ensure the privacy of application users' data. Several studies discussing cyber security (Zhang et al., 2018). Cosgrave et al. (2014) revealed that the use of public data without privatization develops a sense of public distrust towards the government, thereby triggering the destruction of public and government relations in the long term. Therefore, it is essential to carry out data maintenance to increase the level of trust in the community. Reliability is obtained from the increase in application performance to see how big the system failure rate is. Mayangsari and Novani (2015) said that the application had provided environmental and social improvements, thus it must be optimized and innovated according to development needs. The more the reliability of the application increases, the more it will meet the community's expectations with the decreasing number of urban problems and

increasing public and government communication. The government has optimized public services and provided feedback on public reporting. The high level of application reliability is associated with a match between reporting/application use and government response efforts. This study on application reliability with public trust is also in line with the result by [Hu et al. \(2019\)](#), who argued that the security and reliability have a relation to public acceptance of technology which implicates that if the reliability of such platforms is high, then the public will have more trust. The government, which seems to reach out to the poor with its policies, has a higher level of trust.

The next control variable that will be analyzed is education. In this study, the impact of education level is approximated by the years of schooling. The years of schooling varies from 6 (elementary school), 9 (junior high school), 12 (senior high school), 16 (Undergraduate), and up to 20 (Postgraduates). According to the regression result, years of schooling slightly and negatively impact the level of trust in the local government. However, only the case of Bandung was statistically significant at a 99% confidence level. Statistically, an increase of years of schooling by one year will likely increase the level of trust in local government by 0.005 (Jakarta) and decrease by -0.072 (Bandung), -0.009 (Semarang), and -0.02 (Surabaya). The only statistically significant case is Bandung.

This study also conducted a simulation based on the regression model to see how years of schooling affect the trust of local government scores. The result of the simulation is shown in [Fig. 5](#). Based on the regression result, in the case of Jakarta and Semarang, years of schooling negatively impact the level of trust, meaning that more educated residents will tend to trust the local government less. Meanwhile, in Bandung, it has a slightly quadratic effect, meaning that the trust in local government will tend to be lower until a certain level of education. In the case of Surabaya, the trust score will tend to rise as the years of schooling rise. Higher levels of education provide opportunities for individuals to obtain information about government performance. News issues give interest for the public to find out what the government has been doing. Individuals with higher education tend to have higher demands on the government, such as providing a better quality governance, or being more transparent and accountable. [Grimmelikhuijsen et al. \(2013\)](#) stated that high demand for orders is related to a high level of satisfaction on government performance. The expectations of individuals with higher education are higher than those with low education. [Botero and Justice \(2013\)](#) reported that highly educated individuals were likelier to sue or frequently complain to the government. The complaint is seen as a way to improve the government's performance

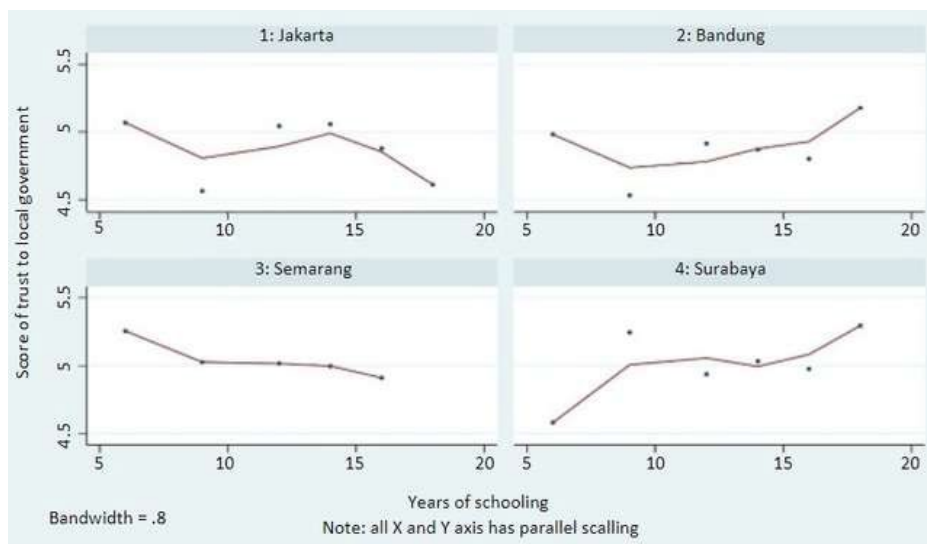


Fig. 5: Impact of years of schooling trust on local government

and encourage the government to improve better governance. The higher a person's knowledge is inversely proportional to the level of trust in the government. Areas with low institutional quality and high levels of non-transparency impact the erosion of government and community relations related to improving the education of their people (Charron and Rothstein, 2016).

The government must continue to improve its performance to reduce distrust among the academic community. A more competent the government, the more they will be more trusted, and vice versa. The government will be viewed as less trustworthy if it is less competent in following community wishes. On the other hand, trust is a strong bond between the community and the government that allows them to work together to build urban areas. The last control variable is the dummy variable of sex/gender. Based on the regression table, the dummy variable of sex (where 1 = male and 0 = female) does not significantly impact the local government's trust score. Statistically, male citizens tend to have more trust scores of -0.01 (Jakarta), 0.088 (Bandung), -0.009 (Semarang), and -0.028 (Surabaya), but the coefficient parameters are not significant. Hence, the correlation between gender and the trust score for local government is inconclusive, both on the regression level and the simulation (Fig. 6). However, previous research stated that gender have correlation to the public trust on

the government (Kim et al., 2017). The results are convergent with the simulation results that have been conducted based on the regression model. The visual result of the simulation is stated in Fig. 5. On the constant, the case of Semarang has the highest initial point of trust (2.84) compared to the other city cases, such as Jakarta (0.78), Bandung (1.48), and Surabaya (2.55). Most constants are significant at a 99% confidence level, except constant in the case of Jakarta. The regression models on each city also have various R-squares. In the case of Jakarta, the variance of the variable dependent can be explained by the variance of the independent variable of 44.6% (Jakarta), 64.9% (Bandung), and 19.9% (Semarang), and 23.1% (Surabaya). Trust and application are a reinforcing cycle (Alzahrani et al., 2017). Trust is the beginning of the willingness to adopt applications by the community, which can affect the return to the level of trust. Public trust is formed through the creation of public value. One strategy for creating public value is through smart city applications (Criado and Gil-Garcia, 2019; Savoldelli et al., 2014). In their study, Criado and Gil-Garcia (2019) explained that public value creation using smart technology. Public value creation is based on data collected by smart city application users. Public value creation has challenges in fulfilling the efficiency of accountability, equity, and response (Cosgrave et al., 2014). An increase in these variables will lead to a boost in confidence.



Fig. 6: Gender on citizens' trust in local government is inconclusive compared to the regression result

The government has successfully communicated the goals of application adoption through smart city applications, resulting in a close correlation. The government has succeeded in achieving its goal of community-based performance improvement. Given the importance of applications in fostering public trust, the previous studies stress the importance of maximizing community application use. However, the issue is that the community's technology literacy rate is still low. The frequency in which users use applications is also low (Afriani *et al.*, 2021). Therefore, it is necessary to encourage building a culture of using applications and reporting to improve urban quality. Another problem is expressed by (Allen *et al.*, 2020). Smart city applications have improved the urban environment, but the scope of improvement is primarily for middle and upper socioeconomic areas, where marginalized areas lack adequate reporting and improvement. Martinez and Masron (2020) revealed that the common use of the internet (digitation) is an obstacle to building trust, which is then associated with the use of smart city applications. There are also still some criticisms of the lack of support for community social inclusion (Paskaleva *et al.*, 2017). Development can be achieved by implementing the effectiveness of sustainable-based governance. Empowerment fosters intelligent communities that foster innovation and collaboration while fostering positive government-community relations (Appio *et al.*, 2019).

## CONCLUSION

After conducting a survey in Jakarta, Bandung, Semarang, and Surabaya, as well as exploring the factors that affect the trust score towards the local government, this study concludes that smart city applications can help build the trust of the community in the government. However, several factors can affect the application's achievement in building citizens' trust, namely: the application's quality, satisfaction, and reliability. These three factors that can affect the public trust, based on the regression analysis, are the application's quality, satisfaction, and reliability, which are found to be statistically significant. The quality of the smart city application has a positive and significant impact on the local government's trust score. The coefficient parameter in each case of the cities is different, while Jakarta has the highest coefficient parameter.

It indicates that the quality of smart city application will increase citizens' trust in their local government. In addition, the smart city application satisfaction significantly and positively impacts the trust score in Jakarta, Bandung, and Surabaya. In other words, the level of user-friendly application could directly impact citizens' trust. Other than that, smart city application reliability also has a positive and significant impact on trust in all cities. This indicates that the more reliable the application, the more it will raise the citizens' trust. However, the coefficient parameter is different for each city. Therefore, one of the government's efforts which should be focused, in terms of smart city development, is to build smart city applications that provides a good quality design, having a reliable content, and gives satisfactory results to the user. This study in investigating the public trust implicates to the empowerment of community. The government can build trust and empower the community through using the result of this study. Based on this study model, the user application's age, years of schooling, and gender did not significantly impact the building process of citizens' trust. In addition, years of education also do not significantly impact the trust level, with the exception in Bandung's case. Those differences in results in Bandung still need to be analyzed further to explore what factors make school years significantly impact a smart city application to build citizens' trust. However, even though the smart city application can build citizens' trust in the government, the community that uses this application is still low. It implies even though previous study shows that the smart city applications can increase interaction, it also becomes an urgency to see other factors on community participation in smart city applications. Furthermore, the differences of coefficient parameters can be a potential future research on investigating other factors that impacted smart city implementation. Therefore, it is necessary to encourage a culture of using those applications to help build citizens' trust in the government and improve urban quality. This study suggested further research on how to increase the use of smart city applications and what aspects impact the usage. In addition, this study also suggests combining this study's results with the result from other cities to represent all types of cities. This is because this study only focuses on the big cities as a sample study.

## AUTHOR CONTRIBUTIONS

H. Herdiansyah as a single author, is responsible for the field research process and writing the manuscript.

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## CONFLICT OF INTEREST

The author declares that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

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## ABBREVIATIONS

$\alpha$	Level of significance
$\epsilon$	Error terms
$\beta_0$	Intercept
$\beta_{-i} (1,2,3 \dots k)$	Coefficient parameter of independent variables
AI	Artificial intelligence
App.	Application
EPI	E-participation index
Eq.	Equation
Est	Estimation model
E-Wadul	<i>Wadah Usulan dan Keluhan</i> (Container for Proposals and Postponing)
Fig.	Figure
Freq.	Frequency
ICT	Information and communication technologies
iOS	iPhone Operating System
IoT	Internet of Things
JAKI	<i>Jakarta Kini</i> (Jakarta Now)
Localgovt	Local government
OLS	Ordinary least squares
R-squared	Coefficient of determination
Satisf	Satisfaction
S.D.	Standard deviation
TAM	Technology acceptance model
$X_i$	Explanatory variables
$X_{-1}$	Score of smart city application quality
$X_{-2}$	Score of smart city's satisfaction from citizens
$X_{-3}$	Score of smart city application reliability
$X_{-4}$	Age (in years)
$X_{-5}$	Years of schooling (in years)
$X_{-6}$	Dummy variable of gender
$\bar{Y}$	Score of trust to local government
$Y_{-sch}$	Years of schooling

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## CASE STUDY

Macroinvertebrate composition as a determinant of larval abundance in the dragonfly, *Miathyria marcella* in tropical wetlandsM.I. Moreno Pallares<sup>1,2\*</sup>, M.A. Bonilla Gómez<sup>1</sup>, G.H. Guillot Monroy<sup>1</sup>, A.C. Torregroza-Espinosa<sup>3</sup><sup>1</sup>Departamento de Biología, Universidad Nacional de Colombia, Bogotá, Colombia<sup>2</sup>Departamento de Biología, Universidad del Atlántico, Puerto Colombia, Atlántico, Colombia<sup>3</sup>Departamento de Productividad e Innovación, Universidad de la Costa, Barranquilla Atlántico, Colombia

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## ABSTRACT

**BACKGROUND AND OBJECTIVES:** Odonate larvae play an important role in macroinvertebrate trophic networks and are excellent indicators of wetland quality. However, despite their ecological importance, research on odonates and how they interact with their environment is scarce. This study aims to assess macroinvertebrate composition as a determinant of larval abundance in *Miathyria marcella* (Odonata: Anisoptera: Libellulidae).

**METHODS:** In total, 29 samples were collected from six wetlands with different types of hydrological influence using standardized invertebrate sampling techniques in Atlántico, a department located in northern Colombia. Standardized invertebrate sampling techniques were used at 29 sampling points. Obtained data were used to analyze invertebrate abundance and a non-parametric multidimensional scaling analysis was applied. In addition, a correlation analysis was conducted between macroinvertebrate composition and *Miathyria marcella* larval abundance.

**FINDINGS:** A total of 2586 larvae and 12925 individual macroinvertebrates were collected, distributed across 25 orders and 58 families. The most abundant orders were Neotaenioglossa (26 percent), Odonata (15 percent) Calanoida (10 percent) and Diptera (8 percent). Heatmap and scaling analysis indicated different macroinvertebrate compositions in the sampled wetlands. It was found a high positive correlation between *Miathyria marcella* and the orders Odonata ( $R^2 = 0.84$ ,  $p\text{-value} \leq 0.05$ ), Coleoptera ( $R^2 = 0.52$ ,  $p\text{-value} \leq 0.05$ ), Basommatophora ( $R^2 = 0.60$ ,  $p\text{-value} \leq 0.05$ ), and Hemiptera ( $R^2 = 0.50$ ,  $p\text{-value} \leq 0.05$ ).

**CONCLUSION:** The results suggest that the abundance of *Miathyria marcella* responds to the accompanying macroinvertebrates, the composition of which depends on the type of hydrological influence. Assessment approaches that focus on the relationships between macroinvertebrate taxa are important conservation tools for biodiversity assessment. Results from this study will serve as a baseline to propose monitoring and follow-up strategies for environmental sustainability in wetlands in this region.

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## INTRODUCTION

Odonates are one of the most familiar insect groups. They are predators relatively large in comparison with other insects and are widely distributed across aquatic environments. More than 6300 species have been described, exhibiting considerable variation depending on their habitat, type of prey consumed, and set of ecological conditions needed for establishing populations (Bybee et al., 2021). Due to their large diversity, easy identification, and high sensitivity, Odonate communities have been used as key bioindicators for verification of ecological integrity of ecosystems, assessment of environmental impacts, and making decisions on conservation measures (Carvalho-Soares, 2022). Several authors have found that this insect order adapts to environmental factors such as light, temperature, water currents, substrate, geography, drought and flooding periods, available food, species competition, biotic and abiotic changes, and anthropogenic changes (Bowles and Kleinsasser, 2022). In this regard, habitat integrity is essential to define their distribution and abundance. Population dynamics within an ecosystem are strongly determined by the trophic chain and its components. In the case of macroinvertebrates, they play an important role in maintaining equilibrium in aquatic environments (Ramírez and Gutiérrez-Fonseca, 2014). As a result, several researchers have analyzed the efficiency of odonates as biological control agents in several ecosystems (Akram and Ali-Khan, 2016). These insects are also important for ecosystem trophic networks, as they are part of the diet of birds, reptiles, fish, and amphibians (Abdul, 2017). Dragonflies are important predators of several macroinvertebrates (Vilenica, 2017). Different authors have used correlation analysis to observe the relationships between dragonflies with different biotic and abiotic variables. González-Soriano et al. (2021) found relationships between Odonata in terms of monthly diversity, that is, taxonomic divergence with monthly precipitation values. Dou et al. (2022) evaluated relationships between species richness, diversity of macroinvertebrates, and biomass of macroinvertebrates. Younes et al. (2015) evaluated the predation potential of *Hemianax ephippiger* (Odonata: Aeshnidae) nymphs on the freshwater snail *Lymnaea natalensis*, intermediate host of *Fasciola*, a liver fluke able to cause livestock losses

and affect human health. They found that dragonflies are ideal pest predators, playing an important regulatory role in ecosystems. Researchers found that nymphs of *H. ephippiger* are a viable option for snail control in freshwater wetlands, contributing to their conservation through biological control (Younes et al., 2015). Mandal et al. (2018) assessed the efficiency of Odonate nymphs for biological control against larvae of the mosquito *Culex quinquefasciatus*. Despite having differing consumption rates depending on the species and developmental stage, nymphs were able to consume a substantial amount of mosquito larvae, increasing their capacity to decrease their numbers. These results highlight the fact that introducing Odonate nymphs into wetlands aids the efficient control of pests and vectors. Table 1 provides an example of recent research on the relationship of Odonata with macroinvertebrates. However, despite the ecological importance of Odonata, research on their interactions with the environment and other macroinvertebrates is scarce. The objective of this study is to evaluate macroinvertebrate composition as a determinant factors in the larval abundance of the Odonate *Miathyria marcella* (Odonata: Anisoptera: Libellulidae). This study was carried out in six wetlands in Atlántico, a department in northern Colombia. Field measurements and laboratory analysis for this study were conducted in 2021.

## MATERIALS AND METHODS

Biological samples were collected and transported to the laboratory for determination of the macroinvertebrate composition. Descriptive analysis was performed and the relationships between macroinvertebrates and larval abundances of *M. marcella* were analyzed using correlation analysis. This research was based on the hypothesis that the abundance of fauna associated with macrophytes in the wetlands of the department of Atlántico is a determinant of the distribution and abundance of *M. marcella* larvae (Odonata: Anisoptera: Libellulidae).

### Study area

The study was performed in Atlántico, a department located in northern Colombia, particularly in the wetlands Totumo (TM), Mallorquín (MQ), Sabanagrande (SG), Larga-Luisa (LL), Tocagua (TG), and Luruaco (LU), all of them locally known as *ciénaga*. Two wetlands (SG and LL) with hydrological influence

Table 1: Summary of recent studies about Odonata's relationship with macroinvertebrates

Location	Relevant aspects	References
Puerto Rico	Freshwater macroinvertebrates play an important role in maintaining food webs. Odonata (dragonflies and damselflies) are important top predators in these communities and serve as indicators of health. Predator-prey interactions and resource competition, may also shape the distribution of a species. For example, macroinvertebrate abundance is often affected by fish predation.	Mariani-Ríos <i>et al.</i> (2022)
Poland	This study evaluated the community composition and diversity and the heterogeneity of macroinvertebrate communities. It was found that habitat heterogeneity influenced benthic invertebrates more than water parameters. Thus, other factors, such as fish predation, may have played a leading role in community shaping.	Czerniawska-Kusza <i>et al.</i> (2022)
Singapore	The biological control potential of odonata larvae was evaluated. Functional response experiments using <i>Aedes albopictus</i> larvae as prey, highlighting their predatory efficiencies at low prey densities and demonstrating that urban odonates can consume substantial numbers of mosquito larvae (up to 44 per day) under experimental conditions. Complementary field-based experiments, however, showed little impact of odonate larvae predation on the overall composition of naturally colonizing aquatic macroinvertebrate communities, but revealed substantial size-selective predation by odonate larvae on mosquito larvae.	Choo <i>et al.</i> (2021)
South Korea	Habitat preferences and trophic level of <i>Brachydiplax chalybea</i> larvae were identified. Stable isotope analysis showed that <i>B. chalybea</i> is likely to consume, as a food source, other species of Odonata larvae.	Choi <i>et al.</i> (2020)
USA	Ecosystem Services indicate that Odonata (dragonflies and damselflies) have some impact as predators of disease vectors and agricultural pests. In addition, their larvae are very important as intermediate or top predators in many aquatic ecosystems.	May (2019)
Cuba	They studied the Odonata's larvae associated with the root system of <i>Eichhornia crassipes</i> . It was determining the taxonomic composition and the trophic structure. The relationship between climatic variables, root volume and density of individuals suggests that the number of rainy days and accumulated rainfall influence in the abundance of certain taxa and that the roots of <i>Eichhornia crassipes</i> can be appraised as an important habitat for dragonflies larvae and a great place to find food for them.	Barbán (2015)

from the Magdalena River, two (TM and MQ) with hydrological influence from the Caribbean Sea, and two (TG and LU) with hydrological influence from seasonal runoff. Sampling sites in the wetlands were selected considering the affluents, effluents, and macrophyte distribution (Fig. 1). Table 2 describes some of the relevant characteristics of the wetlands sampled.

#### Sample collection and preservation

Standardized techniques for macroinvertebrate collection (Correa-Araneda *et al.*, 2021) were used in this study. Macroinvertebrates were collected using a conical net with a diameter of 40 cm, a length of 65 cm, a mesh size of 250 µm, and a metallic handle with a length of 90 cm. The collection method was standardized in each sampling point, five minutes in a 1 m<sup>2</sup> area (Correa-Araneda *et al.*, 2021). Samples

were stored in Ziploc plastic bags containing 70% alcohol, labeled with the respective field data in order to be processed in the laboratory.

#### Macroinvertebrate identification

Collected materials were placed on plastic trays and rinsed with water before separating faunal elements with entomological tweezers. Taxonomic keys were used to identify collected faunal elements to the lowest taxonomic rank possible, and fauna were quantified for each sampling point (Hamada *et al.*, 2018). Sorted macroinvertebrates were deposited in vials containing 70% alcohol and labeled with field data.

#### Data analysis

To assess macroinvertebrate composition as a determinant factor of *M. marcella* larval abundance,

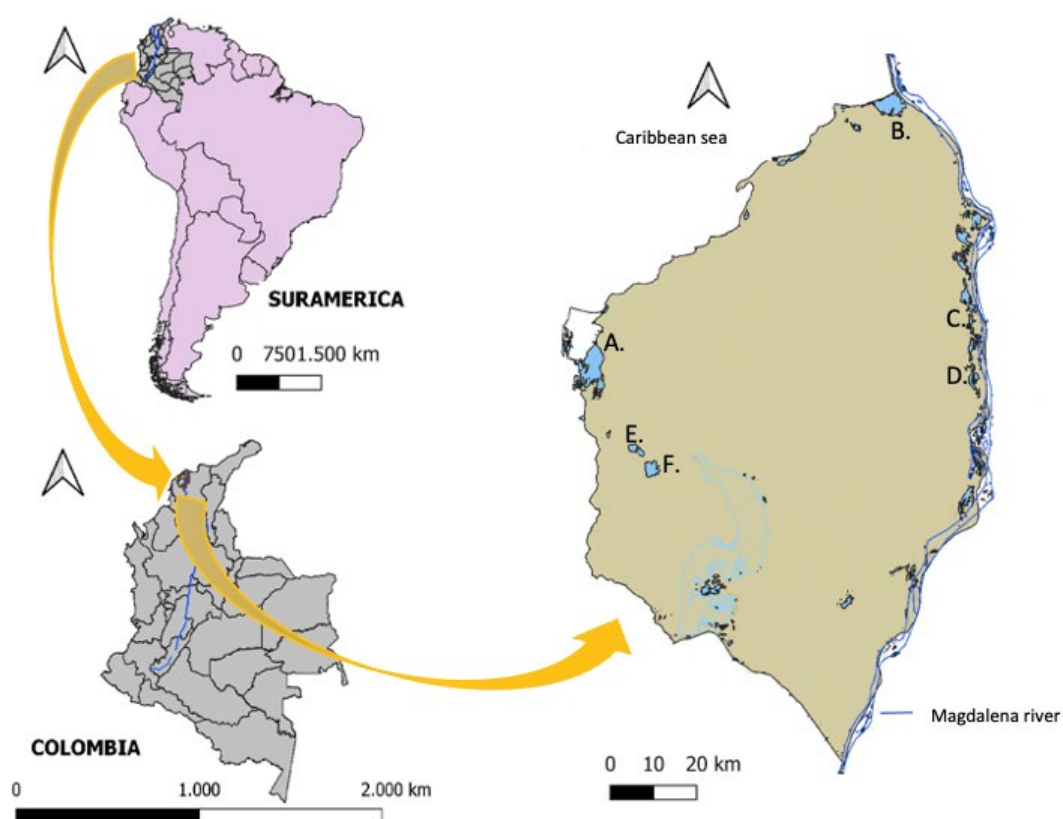


Fig. 1: Geographic location of the studied wetlands and sampling points  
(A. TM wetland; B. MQ wetland; C. SG wetland; D. LL wetland; E. TG wetland; F. LU wetland)

Table 2: Characteristics of wetlands sampled

Wetlands	Hydrological influence	Wetland surface (km)	Max depth/ mean depth (cm)	Water temperature (°C) Mean±SD
TM	Caribbean Sea	Perimeter: 24.80 Max length: 6.9 Max width: 3.5	210/110	30.4±0.2
MQ	Caribbean Sea	Perimeter: 15.90 Max length: 4.0 Max width: 3.1	170/55	28.1±0.2
SG	Magdalena River	Perimeter: 3.15 Max length: 1.12 Max width: 0.60	140/80	31.9±0.4
LL	Magdalena River	Perimeter: 6.92 Max length: 2.90 Max width: 0.38	110/60	30.2±0.3
TG	Local streams	Perimeter: 6.81 Max length: 2.63 Max width: 1.08	180/106	31.8±0.2
LU	Local streams	Perimeter: 7.10 Max length: 2.02 Max width: 1.70	220/84	32.8±0.17

a descriptive analysis with macroinvertebrate compositions and *M. marcella* larval abundance was performed. Macroinvertebrates were organized at the order level. The general distribution was described for each type of hydrological influence. In addition, a heat map was generated and a non-parametric multidimensional scaling (NMDS) analysis was applied using Bray-Curtis distances. Then, a correlation analysis was performed in order to determine the association between macroinvertebrates and larval abundances of *M. marcella*.

## RESULTS AND DISCUSSION

The results were separated into the following categories: *Miathyria marcella* abundances, macroinvertebrate composition, and relationship between macroinvertebrate abundance and *Miathyria marcella*.

### *Miathyria marcella* abundances

A total of 2586 individual *M. marcella* larvae were collected and distributed as follows: 1011 individuals in LL, 486 individuals in TG, 465 individuals in LU, 372 individuals in SG, 239 individuals in TM, and 13 individuals in MQ. Mean and standard deviation were greater in wetlands hydrologically influenced by the Magdalena River (19.4±1.7 individuals in LL and 9.3±1.4 individuals in SG), followed by wetlands

hydrologically influenced by local drainages (8.1±0.4 individuals in RG and 6.4±0.4 individuals in LU). Lastly, abundances were lowest in wetlands hydrologically influenced by the Caribbean Sea (3.9±0.3 individuals in TM and 0.3±0.1 individuals in MQ) (Fig. 2).

The abundance of *M. marcella* differed among the sampled wetlands. The results indicate that abundances were higher in wetlands influenced by the Magdalena River, as well as in those influenced by seasonal drainage. The lowest abundance was found in wetlands influenced by the Caribbean Sea. Mallorquín is a lagoon bound to the north by the Caribbean Sea, and they exchange water sporadically through a connection that is sometimes natural and sometimes artificial (Torres-Bejarano et al., 2020). Lower values in wetlands with Caribbean influence are consistent with the results of Rychla et al. (2011), who assessed the effect of conductivity (113 - 2620 µS/cm) on richness and abundance of dragonfly species. Their results showed that no species was reported in conductivities higher than 1200 µS/cm. In addition, they concluded that high conductivity is harmful for dragonflies. Gómez-Tolosa et al. (2015) pointed out that *M. marcella* is a species that may adapt to different aquatic environments. It has been shown that Odonate abundance is directly related to environmental quality due to the sensitivity of members of this order to environmental changes. The

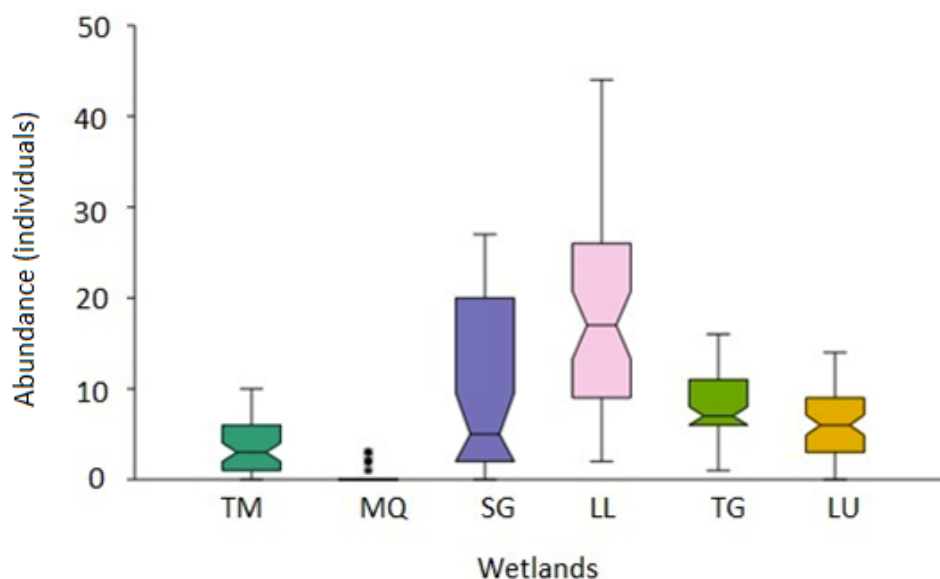


Fig. 2: Abundance of *M. marcella* larvae in sampled wetlands.

most significant threats to freshwater ecosystems are changes in land use that alter sediment loads or nutrient inputs, increase interactions with exotic species, change flow regulation and habitat fragmentation, and alter hydrology (Hecca *et al.*, 2018; Karbassi and Pazoki, 2015).

#### Macroinvertebrate composition

A total of 12925 individuals were collected, distributed across 25 orders and 58 families. Comparing wetland abundances, more individuals were found in LU, with 3496 individuals, followed by wetlands influenced by the Magdalena River, with 2378 individuals, and 2181 individuals in LL and SG, respectively. The abundance in wetlands TG, TM, and MQ was 2142, 1854, and 874 individuals, respectively. The most abundant orders were Neotaenioglossa (26%), Odonata (15%), Calanoida (10%), and Diptera (8%) (Fig. 3). Orders with abundances lower than 1% were Eunicida, Lepidoptera, Megaloptera, Mytiloida, Neogastropoda, Neritopsina, Stylommatophora, Trichoptera, and Unionoida.

Macroinvertebrate composition differed among wetlands. The most abundant orders in TM were

Diptera, with 340 individuals, and Calanoida, with 369 individuals. In MQ, the most abundant group was Neotaenioglossa, with 292 individuals; in SG Odonata, with 404 individuals; LL Odonata, with 545 individuals; and Diplostraca, with 433 individuals. In TG Neotaenioglossa, there were 528 individuals, and Odonata had 526 individuals. LU Neotaenioglossa had 1511 individuals (Fig. 4). Similarly, NMDS results indicated differences in macroinvertebrate abundances among sampled wetlands (Fig. 5).

Insect orders Coleoptera, Diptera, Hemiptera, and Odonata are generally found in lentic systems (Rivera-Usme *et al.*, 2015). However, it was found that Neotaenioglossa (Mollusca), Diplostraca (Crustacea), and Calanoida (Copepoda) were also among the most abundant orders. In studies of coastal wetlands, mollusks and copepods are among the most abundant elements (Suárez-Morales, 2015), which is consistent with the results obtained for wetlands TM and MQ. Diplostracans are important elements of temporal waterbodies. The abundance of this group depends on precipitation frequency and magnitude (Schwentner *et al.*, 2015), being associated with inundation pulses in wetlands LL and SG. Flow increase during rainy

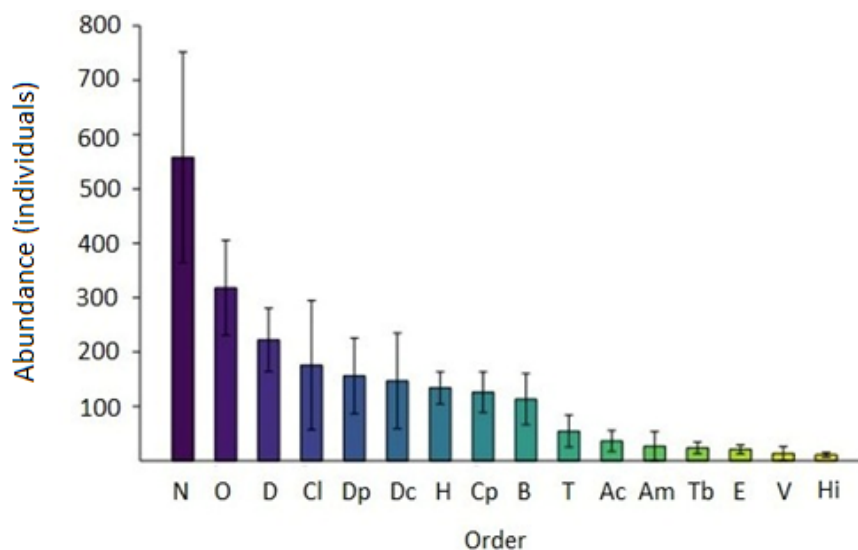


Fig. 3: Macroinvertebrate order abundances. Orders with abundances below 1% were excluded.

Bars represent standard error. N: Neotaenioglossa (Mollusca: Gastropoda). O: Odonata (Arthropoda: Insecta). D: Diptera (Arthropoda: Insecta). Cl: Calanoida (Arthropoda: Maxillopoda). Dp: Diplostraca (Arthropoda: Branchiopoda). Dc: Decapoda (Arthropoda: Malacostraca). H: Hemiptera (Arthropoda: Insecta). Cp: Coleoptera (Arthropoda: Insecta). B: Basommatophora (Mollusca: Gastropoda). T: Tubificida (Annelida: Clitellata). Ac: Architaenioglossa (Mollusca: Gastropoda). Am: Amphipoda (Arthropoda: Malacostraca). Tb: Trombidiformes (Arthropoda: Euchelicerata). E: Ephemeroptera (Arthropoda: Insecta). V: Veneroida (Mollusca: Bivalvia). Hi: Hirudinida (Annelida: Clitellata).

periods has a significant influence on sediment and nutrient load and promotes the fast colonization of species adapted to this type of wetland (Cid *et al.*, 2017). Castillo and Huamantico (2020) indicated that differences in macroinvertebrate composition among wetlands are caused by hydrology, aquatic vegetation,

anthropogenic perturbations, and accompanying faunal elements. Composition differences among wetlands, as indicated by heat map and NMDS, are mediated by these factors along with differences in wetland hydrological influence (Magdalena River, Caribbean Sea, or Seasonal Drainages). In addition,

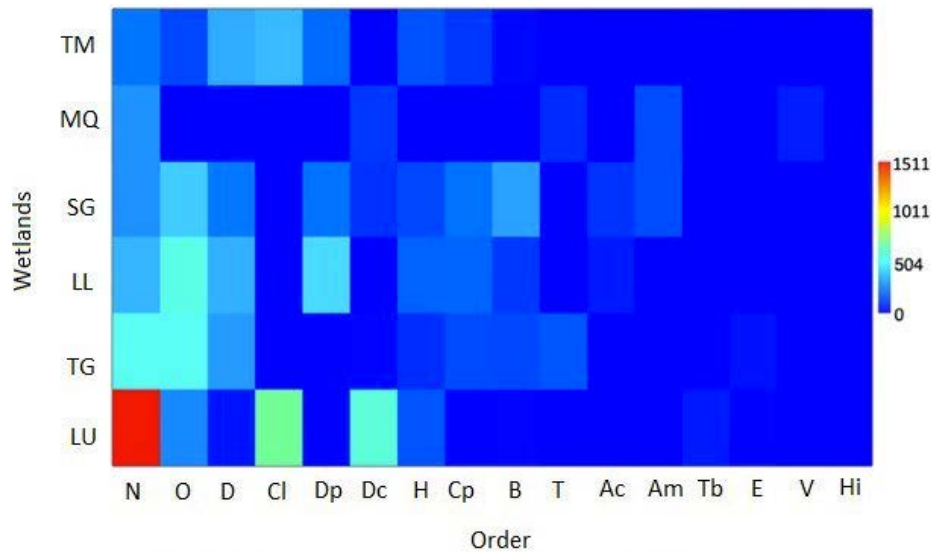


Fig. 4: Macroinvertebrate abundance heatmap in sampled wetlands.

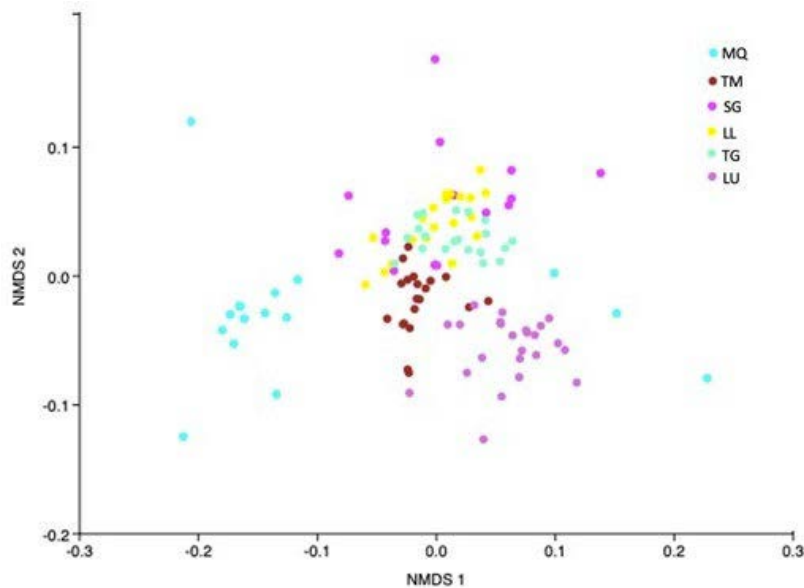


Fig. 5: Non-metric multidimensional scaling (NMDS) based on Bray-Curtis distance. Ordination plot illustrating differences in macroinvertebrate abundance between wetlands

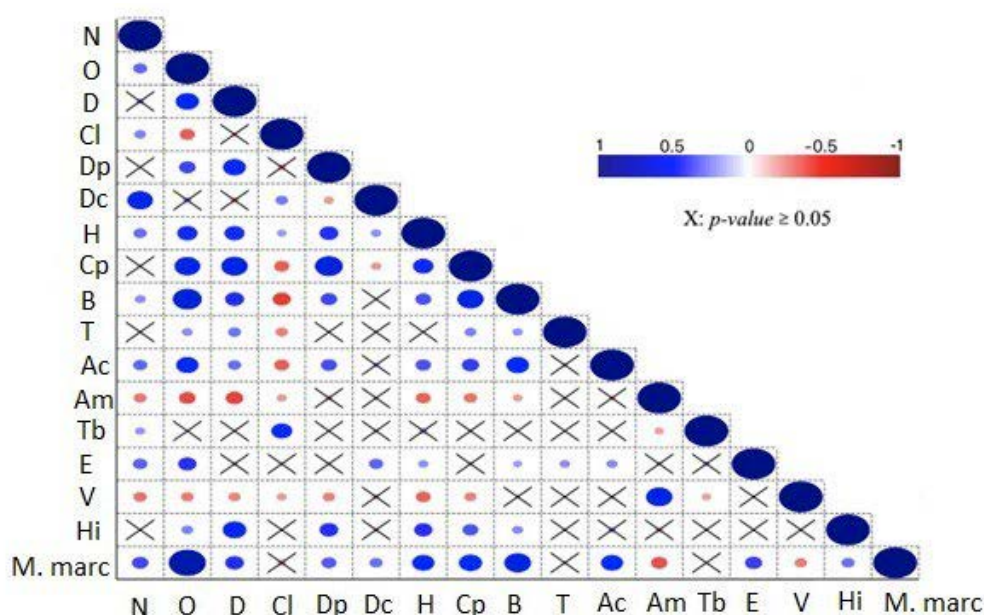


Fig. 6: Spearman correlation matrix between abundances of macroinvertebrate orders and *M. marcella* ( $p$ -value  $\leq 0.05$  blank). N: Neotaenioglossa. O: Odonata. D: Diptera. Cl: Calanoida. Dp: Diplostraca. Dc: Decapoda. H: Hemiptera. Cp: Coleoptera. B: Basommatophora. T: Tubificida. Ac: Architaenioglossa. Am: Amphipoda, Tb: Trombidiformes. E: Ephemeroptera. V: Veneroida. Hi: Hirudinida. M.marcc: *M. marcella*.

Tonkin *et al.* (2017) and Guellaf *et al.* (2021) found seasonal changes in macroinvertebrate community composition and structure due to environmental fluctuations including precipitation and caudal regime.

#### Relationship between macroinvertebrate abundance and *Miathyrja marcella*

Spearman correlation values indicated statistically significant correlations between some analyzed variables ( $p$ -value  $\leq 0.05$ ). A high positive correlation was found between *M. marcella* and the orders Odonata ( $R^2 = 0.84$ ,  $p$ -value  $\leq 0.05$ ), Coleoptera ( $R^2 = 0.52$ ,  $p$ -value  $\leq 0.05$ ), Basommatophora ( $R^2 = 0.60$ ,  $p$ -value  $\leq 0.05$ ), and Hemiptera ( $R^2 = 0.50$ ,  $p$ -value  $\leq 0.05$ ) (Fig. 6).

The correlation found between *M. marcella* and the orders Odonata, Coleoptera, and Hemiptera can be explained by the high dispersal ability of these insect groups in a wide variety of aquatic environments. These groups inhabit all types of freshwater and brackish environments, from small ponds to lakes, wetlands, and streams (Guellaf *et al.*, 2021), tolerating a wide variety of environmental and anthropogenic stressors at different spatial

and temporal scales (Abdul *et al.*, 2017). Similarly, the relationship between *M. marcella* and these orders may be caused by their tropic relationships, as they are potential dietary elements. Different authors have used correlation analysis to observe the relationships between dragonflies with different biotic and abiotic variables. González-Soriano *et al.* (2021) found relationships between Odonata in terms of monthly diversity, that is, taxonomic divergence with monthly precipitation values. Dou *et al.* (2022) evaluated relationships between species richness, diversity of macroinvertebrates, and biomass of macroinvertebrates. However, experimental observations have shown that Odonate larvae are cannibals, and also consume Coleopterans (Fulan and Anjos, 2015), Basommatophorans (Younes *et al.*, 2015), and Hemipterans (Kondo *et al.*, 2015). Adult and larval Odonates play an important role, both as predators and prey of other animals (Samanmali *et al.*, 2018). It is important to assess which macroinvertebrates serve as food for Odonates, as predation affects species abundance, population dynamics, and community structure (Mariani-Ríos *et al.*, 2022). Macroinvertebrates

have long been used as proxies for environmental status, particularly in the context of water pollution and habitat perturbation (Buczynska and Buczynski, 2019). Among orders related to *M. marcella* abundance, there are different responses to environmental factors and perturbations. However, they are considered to be tolerant to water pollution (Silva et al., 2020). Assessment approaches that focus on macroinvertebrate relationships are important conservation tools for evaluation of biodiversity. Assessment of *M. marcella* larvae is intended to provide information on distribution and abundance, in relationship to the accompanying fauna. Studies including estimates of *M. marcella* accompanying fauna will contribute to a better understanding and management of wetlands.

## CONCLUSIONS

Abundance values for *M. marcella* larvae along with macroinvertebrate composition differed among sampled wetlands. A total of 12925 individual macroinvertebrates were collected. The most abundant orders were Neotaenioglossa, Odonata, Calanoida, and Diptera. Heatmap and scaling analysis indicated different macroinvertebrate compositions in the sampled wetlands. It was found a high positive correlation between *Miathyria marcella* and the orders Odonata, Coleoptera, Basommatophora, and Hemiptera. Hydrological influence has a significant effect on this distribution, as their abundance was greater in wetlands hydrologically influenced by the Magdalena River, followed by those hydrologically influenced by seasonal drainages, and with the lowest abundance in wetlands hydrologically influenced by the Caribbean Sea. *M. marcella* is a species that may adapt to different aquatic environments. It has been shown that Odonate abundance is directly related to environmental quality, due to the sensitivity of members of this order to environmental changes. Composition differences among wetlands, as indicated by heatmap and NMDS, are mediated by hydrology, aquatic vegetation, anthropogenic perturbations, and accompanying faunal elements, along with differences in wetland hydrological influence (Magdalena River, Caribbean Sea, or seasonal runoff). Due to their great diversity, easy identification, and high sensitivity, Odonate communities have been used as key bioindicators to verify the ecological integrity of ecosystems and

assess environmental impacts. Results suggest that *M. marcella* abundances respond to accompanying invertebrate groups, particularly the orders Coleoptera, Basommatophora, and Hemiptera. This relationship may be associated with the importance of these orders for Odonate diets. Future research should consider physicochemical variables of water, as they may help to complement and understand macroinvertebrate distribution in wetlands. Without a proper knowledge of distribution for these invertebrate groups, it is not possible to advance conservation efforts. The results of this study will serve as a baseline to propose monitoring and follow-up strategies for the environmental sustainability of wetlands in the Colombian Caribbean. Composition and abundance of macroinvertebrates were assessed using simple techniques, which implies that this methodology can be replicated in other study areas.

## AUTHOR CONTRIBUTIONS

M.I. Moreno Pallares performed literature review, experimental design, analyzed and interpreted the data, writing original draft, writing review and editing. M.A. Bonilla Gómez experimental design, writing original draft, writing review and editing. G.H. Guillot Monroy experimental design, writing original draft, writing review and editing. A.C. Torregroza-Espinosa performed literature review, analyzed and interpreted the data, writing review and editing.

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## CONFLICT OF INTEREST

The author declares that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

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#### ABBREVIATIONS

%	Percentage
°C	Degree centigrade
±	Plus-minus sign
>	Greater-than sign
≤	Less than or equal to
μS/cm	Conductivity unit
Ac	Architaenioglossa
Am	Amphipoda
B	Basommatophora
Cl	Calanoida
cm	Centimetre
Cp	Coleoptera
D	Diptera
Dc	Decapoda
Dp	Diplostraca
E	Ephemeroptera
Fig.	Figure
H	Hemiptera
<i>H. ephippiger</i>	<i>Hemianax ephippiger</i>
Hi	Hirudinida
km	Kilometer
LL	Larga-Luisa wetland

LU	Luruaco wetland
<i>M. marc</i>	<i>M. marcella</i>
<i>M. Marcella</i>	<i>Miathyria marcella</i>
m <sup>2</sup>	Square meter
masl	Meters Above Sea Level
Max	Maximum
mm	Millimetre
MQ	Mallorquín wetland
N	Neotaenioglossa
NMDS	Non-metric multidimensional scaling
O	Odonata
<i>p-value</i>	Statistical significance
R <sup>2</sup>	R-squared
SD	Standard deviation
SG	Sabanagrande wetland
T	Tubificida
Tb	Trombidiformes
TG	Tocagua wetland
TM	Totumo wetland
V	Veneroida

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## CASE STUDY

# Rice suitability mapping using the analytic hierarchy process approach in a river catchment

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## ABSTRACT

**BACKGROUND AND OBJECTIVES:** Land suitability analysis is a technique of attaining optimum utilization of natural available land resource. This study is the first attempt to map the potential rice suitability zone besides the existing rice cultivation zone in Imphal-Irui River catchment. The overriding objective of this study is to identify the land suitability potential zones for rice crop cultivation. The study was carried-out in Imphal-Irui River catchment, Manipur, India.

**METHODS:** The suitability analysis was carried-out based on soil, climate and topographic parameters as the input variable using integrated geographical information system and analytic hierarchy process, a multi criteria decision based approach. To compute criteria weight for various suitability classes, pairwise comparison matrix was applied using analytical hierarchy process and the resulting weights were used for assigning criteria ranking.

**FINDINGS:** The study result indicates that the major section of high and moderate potential suitability zones of rice is concentrated in the flatter valley regions of the catchment. The result also indicates that there is 79.15 km<sup>2</sup> of the area which can be potentially cultivated other than the existing agriculture cover. The major patches of such zones are found in the north-western portion of the valley region in the catchment.

**CONCLUSION:** This study clearly indicates, the potential zones lying in the foothills in the north-western which are still not under the agriculture cover have the potential to be cultivated as per the model result. The model result clearly indicates the potential of geographical information system integrated with analytical hierarchy process technique can be utilized to decide the weights of each individual parameter using experts' opinions which can serve as a versatile tool to carry-out such kind of analysis which can aid policy makers.

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## INTRODUCTION

Rice (*Oryza Sativa*) is the primary cereal food crop for more than 60 percent (%) of the world's population. Globally, rice is produced in many countries but Asia alone accounts for more than 90% of the world rice production and consumption (Naidu *et al.*, 2006) and they are grown successfully in tropical and sub-tropical regions (FAO, 2004). Rice is the major cereal crop in India having a total cultivable area of about 180 million hectares, even in North-East part of India it is the primary staple food crop. In Manipur state of North-East India, 90% gross crop area is under rice production (Singha and Mishra, 2015). Out of 95% of the entire state of Manipur's food grains production, 72% of the total cropland area is rice production (Santosh and Bera, 2017). Agriculture is the backbone of the state economy and majority of the people are involved in agriculture and allied sectors (Roy *et al.*, 2018). In Manipur, rice crop is cultivated predominantly in kharif season (June to November). In the valley region of Manipur, cultivable area have been decreasing day by day due to urbanization, construction and development activities, rendering an assessment of agricultural land suitability and mapping scope of sustainable agricultural development inevitable (Akpoti *et al.*, 2019). Optimum rice production is necessary through sustainable agriculture practice system. Sustainable agriculture concept involves producing good quality product, generally acceptable and economically efficient way by ensuring optimal utilization of natural available resources and target crops (Jules and Zareen 2014; Struik and Kuyper 2017). Sustainable agriculture requires growing the best suited crop for the specific region which further necessitates the analysis of land suitability (Kihoro *et al.*, 2013; NissarAhmed *et al.*, 2000). It is based on finding the requirements of crop and its corresponding land features class (Mugiyo *et al.*, 2021; Bock *et al.*, 2018). Thus, suitability analysis measures how well fit the qualities of land unit is with the requirements of a particular form of land used (Hamere and Teshome, 2018; FAO, 1976). Land suitability based on agriculture is an important assessment for future planning and development, and it also help to the decision makers and planners (Mohamed *et al.*, 2016). In the past decades Multi-Criteria Evaluation (MCE) integrated with Geographical Information System (GIS) has been used to assess the suitability potential (Anand *et al.*, 2021; Bandira *et al.*, 2021). GIS integrated with MCE is useful because various

variables which impact the production is evaluated and are weighted as per their relative importance in optimal crop's growth condition (Perveen *et al.*, 2007). Multi-criteria decision method like analytical hierarchy process (AHP) has been integrated with GIS. Geospatial technology which includes remote sensing, GIS and global positioning system (GPS) have been implemented in different parts of the world to assess the land suitability, to enhance the crop productivity and reduce environmental footprints and cost for input material (Dhami *et al.*, 2012). The main advantage of GIS based techniques over the other used techniques is the scale of application. Other techniques are limited to plot scale or a sub-regional scale and consume more human effort along with cost of equipments, whereas GIS based techniques are cost effective and can be applied over a vast land coverage using aerial or satellite datasets (Yalew *et al.*, 2016). Furthermore, the integration of AHP and GIS-based techniques in assessing land suitability has excellent prospects to enhance the efficiency and accuracy of findings. Using the AHP method of the MCDA technique with GIS is a valuable method for diversifying the crops and cropping systems for obtaining better output from agriculture-food systems (Jain *et al.*, 2020; Kihoro *et al.*, 2013). GIS allows the build-up of models using a new thematic map that can be developed from a set of thematic maps which is easier to visualize for the decision or policy makers. There have been only few studies carried out on rice productivity, socio-economic inter-relationship (Bidyapati and Kaushal, 2020), and trend analysis (Ria *et al.*, 2020). This study is the first attempt in Imphal-Irui catchment to identify the potential rice cultivation suitability zone other than the existing agricultural cover. The main objective of this study is to identify potential cultivation site of rice for optimum production, and compare the suitability zones with existing agricultural lands. The current study was carried out based on the datasets between the time periods 2000-2019 in Imphal-Irui catchment, India.

## MATERIALS AND METHODS

### Study area

Manipur is situated in the North-Eastern region of India and covering an area of 22,327 Square kilometer (km<sup>2</sup>). It consists of 90% of hilly area and remaining 10% has the valley area. The valley has slope from north to south direction and having

annual average rainfall of 1467 millimetre (mm) (DOE, 2013). Imphal-Irui River catchment is considered as the present study area and it is located in the North-Eastern portion of the state. Geographical location of the present study area is shown in Fig. 1. Agricultural land, vegetation, settlement, bare soil and water bodies are the different land use classes present in this catchment. In the study area the natural vegetation comprises of many diversities of plants including grasses, bamboos and numerous species of tree. Hill terrain is occupied by medium to thick tropical deciduous forest. Agriculture is the main state economy and therefore, more than 75% of the people living in this area are involved in agricultural activities and allied sectors and experiences the humid climate with seasonal water deficiency (Sen *et al.*, 2006). The Hydrochemical composition and quality of rivers and the river beds have always been influenced by natural and unnatural (Pollution) factors (Karbassi and Pazoki, 2015).

#### Dataused

Important parameters used in this suitability analysis are climate data (temperature, rainfall), soil data (texture, depth, drainage, soil pH) and topography. These parameters were carefully selected based on local expert knowledge, data availability, literatures review and researcher. Climate Data: crop growth, developments and productivity of rice is very much depending on various climatic factors. From these various factors, rainfall and temperature were selected in this suitability analysis. Rice is normally grown in tropical and sub-tropical region at a temperature between 20 °C to 40 °C with an annual average rainfall greater than 1250mm. Twenty years tropical rainfall measuring mission (TRMM) daily rainfall and moderate resolution imaging spectrometer (MODIS) (MOD11A1) surface temperature data were used in this study. The detail information regarding the data is described in Table 1.

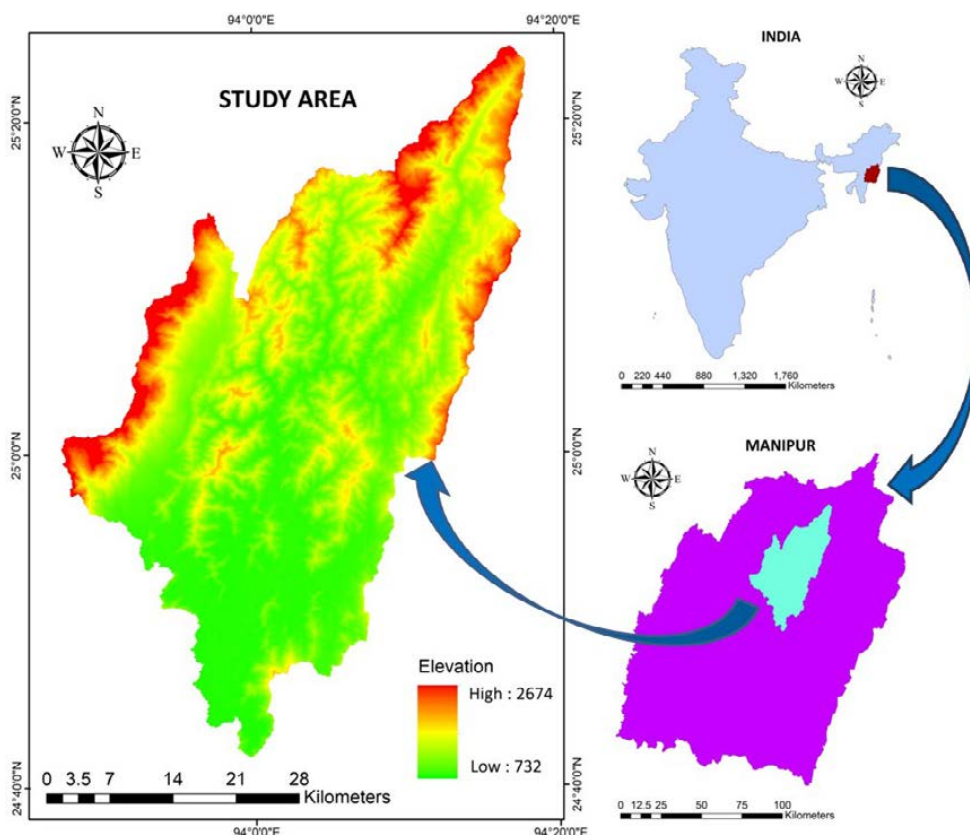


Fig. 1: Geographic location of the study area in the land suitability potential zones for rice crop cultivation along with land use/ land cover in the Imphal-Irui River catchment, Manipur, India

### Soil data

Soil is one of the basic components for agriculture environment as it provides structure support and nutrient to the plant's growth. Good knowledge of chemical and physical properties of soil is required for land suitability analysis. Some important soil parameters used in this study are soil texture, soil drainage, soil depth, and soil pH (Karbassi and Heidari, 2015). These soil information data were obtained from national bureau of soil survey and land use planning and Indian council for agricultural research (NBSS and LUP and ICAR) (Senet *et al.*, 2006).

### Topography

The important topographic element for the application for land suitability analysis is slope and it can be assisted in site and suitability analysis. Slope is generally computed from digital elevation model (DEM). The shuttle radar topography mission (SRTM) DEM having spatial resolution of 30 metre (m) was used to compute elevation using spatial analyst tools in ArcGIS 10.3. Steeper terrain is observed when the slope value is high, whereas flat surface terrain

is observed when the slope value is low. The terrain having smooth surface are more suitable for rice production since water can be distributed uniformly in all directions.

### Multispectral data

The multispectral remote sensing images of Landsat-8 (OLI+TIRS) of the study area were collected from United States Geological Survey (USGS) Earth Explorer. Landsat-8 imagery data has a temporal resolution of 16 days having a spatial resolution of 30 m. The present LULC map of Imphal-Irili catchment was generated using the Landsat-8 imagery data in ArcGIS 10.3 with maximum likelihood classifier tool. The parameters used in this study are described in Table 1.

The requirement of rice suitability was obtained from NBSS and LUP (Naidu *et al.*, 2006). All the parameters are developed in raster data format to run the suitability model in ArcGIS 10.3. Raster datasets were converted into Universal Transverse Mercator (UTM) coordinate system having zone 46N and resample into a spatial resolution of 30 m. The input

Table 1: Description of input parameters

Parameter/satellite	Description	Resolution
Rainfall	20 years(2000-2019)	25 km
Temperature	20 years(2000-2019)	1 km
soil data	Texture, Depth, Drainage, pH	-
Slope	Year-2019	30 m
Multispectral data	Year-2019	30 m

Table 2: Suitability criteria for rice (NBSS and LUP) (Naidu *et al.*, 2006)

Parameter	Unit	Highly suitable(S1)	Moderately suitable(S2)	Marginally suitable(S3)	Not suitable(N)
Rainfall	mm	1110 - 1250	900 – 1110	750 - 900	< 750
Temperature	Celsius	30 - 34	21-29 & 35-38	15-20 & 39-40	< 15 & > 40
Soil Texture	Class	C, SIC, CL, SICL,SC	SCL, SIL, L	SL, LS	S
Soil Depth	cm	>75	51 – 75	25 - 50	< 25
Soil Drainage	Class	Imperfectly drained	Moderately drained	Well drained	Excessively drained
Soil pH	1:2.5	5.5 - 6.5	4.5 - 5.4	7.6 - 8.5	> 8.5
Slope	%	0 - 2	1 – 2	3 - 5	> 5

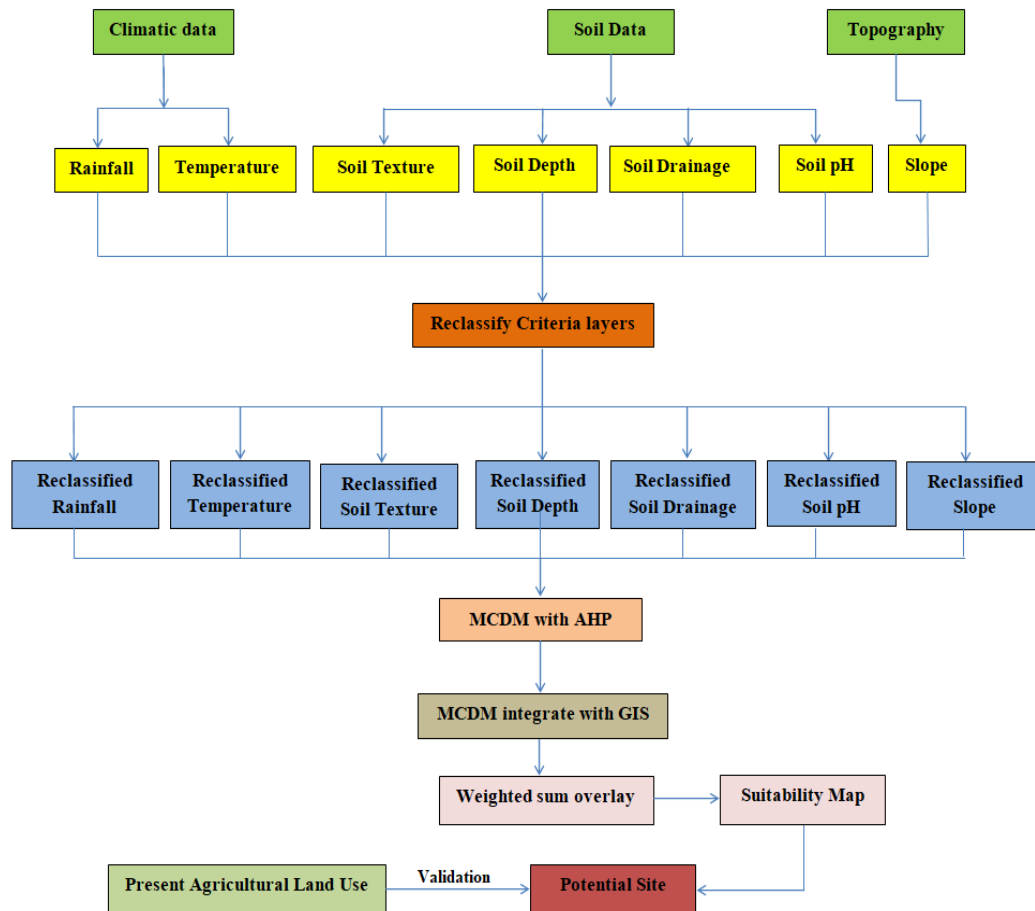


Fig. 2: Methodological approach for rice suitability mapping

datasets were reclassified into different suitability classes based on NBSS and LUP and ICAR classification using spatial analyst tool in ArcGIS. These classified layers rating are shown in Table 2. Based on Food and Agriculture Organisation (FAO, 1976) land suitability classification, suitability class for the parameters used in this study were ranked as highly suitable (S1), moderately suitable (S2), marginally suitable (S3) and not suitable (N). The overall methodological approach for rice suitability analysis is shown in Fig. 2.

#### Analytical hierarchy process and assigning criteria weight

AHP is a multi-criteria decision making method and it is extensively used by many researchers for various studies (Saaty, 1980). This method can be integrated with GIS for various suitability modelling

(Marinoni, 2004). In this method one of the crucial steps is to assign weight to the input data with high degree of precision. It is necessary to determine the rate or relative importance for each criterion present in the decision making problem (Saaty, 1980). Pairwise comparison matrix proposed by Saaty (1980) has been applied for decision making method in this study. Simultaneously, factor weights were determined through comparison of the two factors by using pairwise comparison matrix. In this comparison matrix a scale having the value range from 9 to 1/9 was applied as per scale provided by Saaty (1980). A score of 9 in the rating value indicates the row factor is extremely important than the column factor. Subsequently, a score of 1/9 in the rating scale indicates the column is more important over row factor. Furthermore, a score of 1 in the rating

Table 3: Pairwise comparison matrix

Parameter	Temperature	Rainfall	Soil texture	Slope	Soil pH	Soil depth	Drainage
Temperature	1	1/3	1/5	1/3	3	5	3
Rainfall	3	1	1/3	3	7	5	5
Soil Texture	5	3	1	3	7	5	5
Slope	3	1/3	1/3	1	7	7	3
Soil pH	1/3	1/7	1/7	1/7	1	1	1/5
Soil Depth	1/5	1/5	1/5	1/7	1	1	1/3
Drainage	1/3	1/5	1/5	1/3	5	3	1

Table 4: Normalized comparison matrix

Parameter	Temperature	Rainfall	Soil texture	Slope	Soil pH	Soil Depth	Drainage	Weight	Ranking
Temperature	0.08	0.06	0.08	0.04	0.10	0.19	0.17	0.10	4
Rainfall	0.23	0.19	0.14	0.38	0.23	0.19	0.29	0.24	2
Soil Texture	0.39	0.58	0.42	0.38	0.23	0.19	0.29	0.35	1
Slope	0.23	0.06	0.14	0.13	0.23	0.26	0.17	0.17	3
Soil pH	0.03	0.03	0.06	0.02	0.03	0.04	0.01	0.03	7
Soil Depth	0.02	0.04	0.08	0.02	0.03	0.04	0.02	0.04	6
Drainage	0.03	0.04	0.08	0.04	0.16	0.11	0.06	0.07	5
CR=0.06	Eigen value = 7.48							$\Sigma = 1$	

Table 5: Random index (RI)

Order Matrix(n)	1	2	3	4	5	6	7	8	9	10
Random Index (RI)	0.0	0.0	0.58	0.90	0.12	1.24	1.32	1.41	1.45	1.49

value indicates its equal importance (Saaty, 1977). A value of unity is assigned to diagonal elements once a criteria factor is compared with itself. Pairwise comparison matrix and normalized comparison matrix developed for this study are shown in Tables 3 and 4 respectively. In this method, only triangular half portion of matrix needs to fill since the matrix is symmetrical. The weights of individual parameters to construct the pairwise comparison matrix were allocated based on literature survey and through questionnaires with the experts of agricultural domain. Thus, the remaining elements are simply reciprocal of another half portion. For example, if the rating of rainfall with respect to temperature is 3, than rating of temperature with respect to rainfall is 1/3. In order to generate the normalized comparison matrix, the individual components of the matrix were divided with its corresponding sum of the column. Later, based on the sum of the rows of normalized comparison matrix was divided with the number of parameters to generate the weights of individual

parameters. It is necessary to check the pairwise comparison matrix is consistent or not. As per the AHP model, pairwise comparison matrix should be consistent. The resultant consistency Index (CI) for the matrix is calculated using the Eq. 1 (Saaty 1977).

$$CI = (\lambda_{max} - n) / (n - 1) \quad (1)$$

Where,  $\lambda_{max}$  is maximum the Eigen value and n is the number of criteria of the comparison matrix.

Then, the Consistency Ratio (CR) is calculated for the corresponding n value of random index (RI) using the following Eq. 2 (Saaty 1977). The value of RI is obtained from Table 5.

$$CR = \frac{CI}{RI} \quad (2)$$

If the CR value is less than 0.1, it indicates that the comparison matrix is significant and the judgement is correct (Saaty 1977; Park et al., 2011). For this comparison matrix, the CR value of 0.06 was

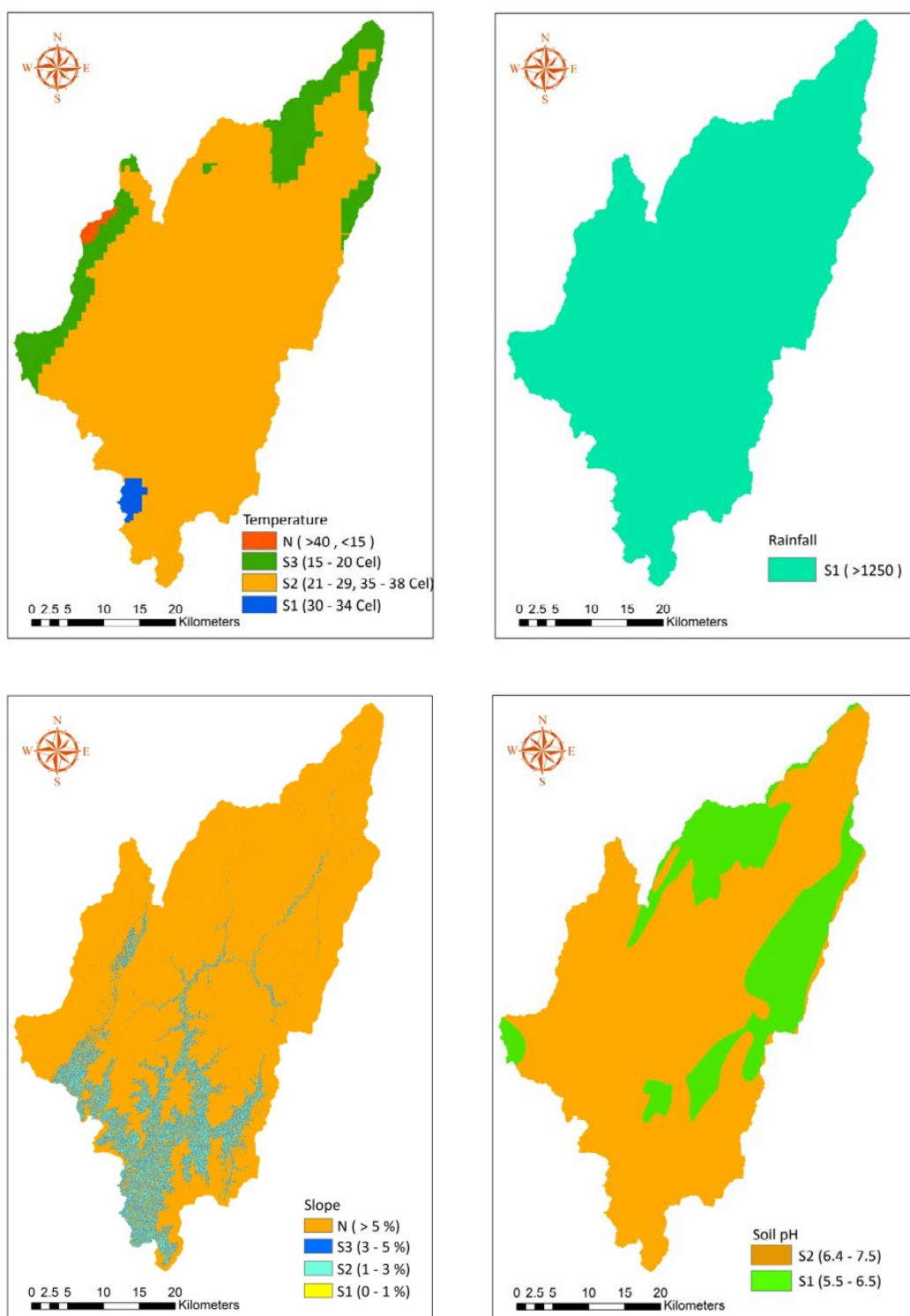
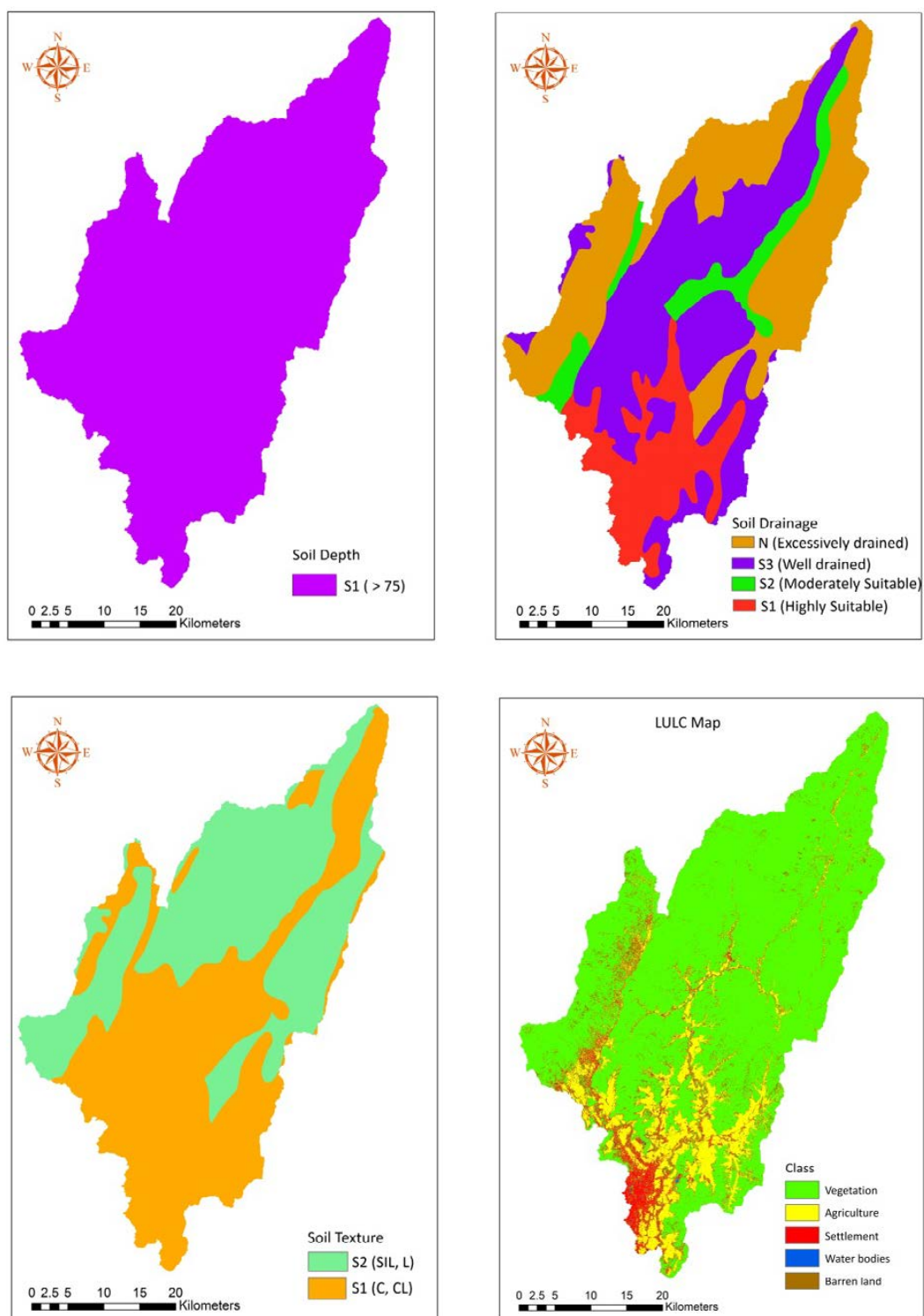


Fig. 3: Suitability level for selected parameters: temperature, rainfall, soil texture, slope, pH, soil depth, soil drainage and land use land cover (LULC)

### Rice suitability mapping using AHP approach



Continued Fig. 3: Suitability level for selected parameters: temperature, rainfall, soil texture,slope,pH, soil depth, soil drainage and land use land cover (LULC)

Table 6: Parameters with its assigned rates and their corresponding weights

Parameters	Range	Rating	Weight
Rainfall	>1100 mm	4	0.24
	900-1100 mm	3	
	750-900 mm	2	
	<750 mm	1	
Temperature	>29 °C	4	0.10
	21-29 °C	3	
	15-21 °C	2	
	<15 °C	1	
Soil Texture	Clayey, clay loam	4	0.35
	Silty loam, loam	3	
Soil Depth	>75 cm	4	0.04
	Imperfectly drained	4	
Soil drainage	Moderately drained	3	0.07
	Well drained	2	
	Excessively drained	1	
Soil pH	5.5-6.5	4	0.03
	4.5-5.4	3	
Slope	0-1 %	4	0.17
	1-3 %	3	
	3-5 %	2	
	>5 %	1	

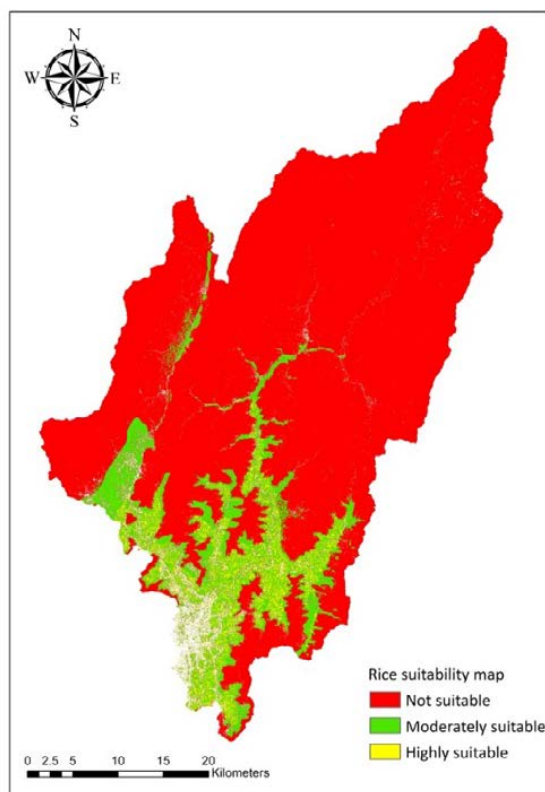


Fig. 4: Suitability map for rice crop

obtained. The result shows that the comparisons of these parameters are consistent and matrix is highly significant.

In this suitability analysis the input parameters were standardized to a scale from 1 to 4 since parameters were collected from different sources (Ahmad *et al.*, 2021). Thus, all criteria were classified into 4 classes that ranges from a score of 1 to 4 based on its different land suitability class. The highest suitability is indicated by the score value 4 and the least suitability is indicated by the score value of 1. The map of suitability levels for seven parameters use in this study are shown in Fig. 3.

Weighted sum overlay technique has been applied to compute rice suitability mapping through spatial analyst tools in ArcGIS 10.3. It is a technique to create an integrated analysis by applying a common scale of value for different input data (Kuria *et al.*, 2011). Different raster layers with their corresponding criteria weights were assigned as per to AHP procedure. The rating and assigned weight of each parameter is shown in Table 6. Then the selected land suitability criteria weights are multiplied by assigned rating score of suitability class (Raster layers). The final suitability map was computed by adding the resulting the cell values as shown in Fig. 4 and the resulting suitability map was classified as highly suitable, moderately suitable, marginally suitable and not suitable. Thus, we obtained the spatial distribution for different suitability classes for rice cultivation in the catchment.

## RESULTS AND DISCUSSION

### *Suitability assessment of rice in the catchment*

The land suitability analysis for rice production was carried out for the whole Imphal-Iril sub-catchment which includes both valley and hilly terrain region. Later, the land suitability for rice was extracted particularly for the valley and foot hills region of the catchment with gentle slope as the hilly regions especially in the mid and upper reaches is covered mostly by evergreen and deciduous forest. The rice suitability map identified by weighted overlay method embedded in tool box of ArcGIS is shown in Fig. 4. From the rice suitability map in Imphal-Iril sub-catchment it can be observed that, highly suitable class covers an area of about 60 km<sup>2</sup> which is characterized by slope value range of 0 - 1%, soil pH value of 5.5 – 6.5, soil depth of greater

than 75 centimetre (cm), soil texture class-clay, silty-clay, clay-loam, sandy-clay, annual average rainfall ranges between 1110-1250 mm, soil drainage- imperfectly drained and temperature between 30-34 °C. From the analysis it was observed that the highly suitable zones are mostly located in the flatter valley regions of the current existing agricultural land of the catchment. Moderately suitable area for rice production was spread over an area of 211.6 km<sup>2</sup>. This class were characterised by slope value range of 1- 3%, pH level between 6.4-7.5 and 4.5-5.4, soil drainage -moderately well drained, soil texture-sandy clay loam, silt loam and loam, temperature between 35 °C– 38 °C and rainfall in between 900 and 1110 mm. From the land suitability map it can be observed that the moderately suitable zones were mainly concentrated in the valley and the foot hill regions of the catchment with the milder sloping topography. From the model output result it was found that marginally suitable and not suitable class were found only in the higher hilly reaches. Large considerable amount of area was found under not suitable and marginally suitable class as compared to other suitability classes. It is because due to the presence of large hilly regions, natural wildlife habitat area and protected reserved forest area. Primarily, hilly regions having high slope profile are not suitable for agricultural activities particularly for rice crop and secondarily, those regions are covered with dense evergreen and deciduous forest which cannot be slashed due to this, not suitable and marginally suitable class were merged together. The results indicate that highly and moderately suitable zones are significantly located in the lower flatter regions of the catchment. To further extract the potential suitability region and existing agricultural region the study was carried focusing particularly the flatter valley region of the sub-catchment.

### *Potential area for rice cultivation in the valley region of the catchment*

The land suitable for the rice cultivation was extracted from the valley region of the catchment using Structured Query Language (SQL). In the valley region of the catchment only two suitability class were observed, that is, highly suitable class and moderately suitable class. From the suitability result at the valley level it was observed that the area coverage under highly and moderately suitable class was found to be

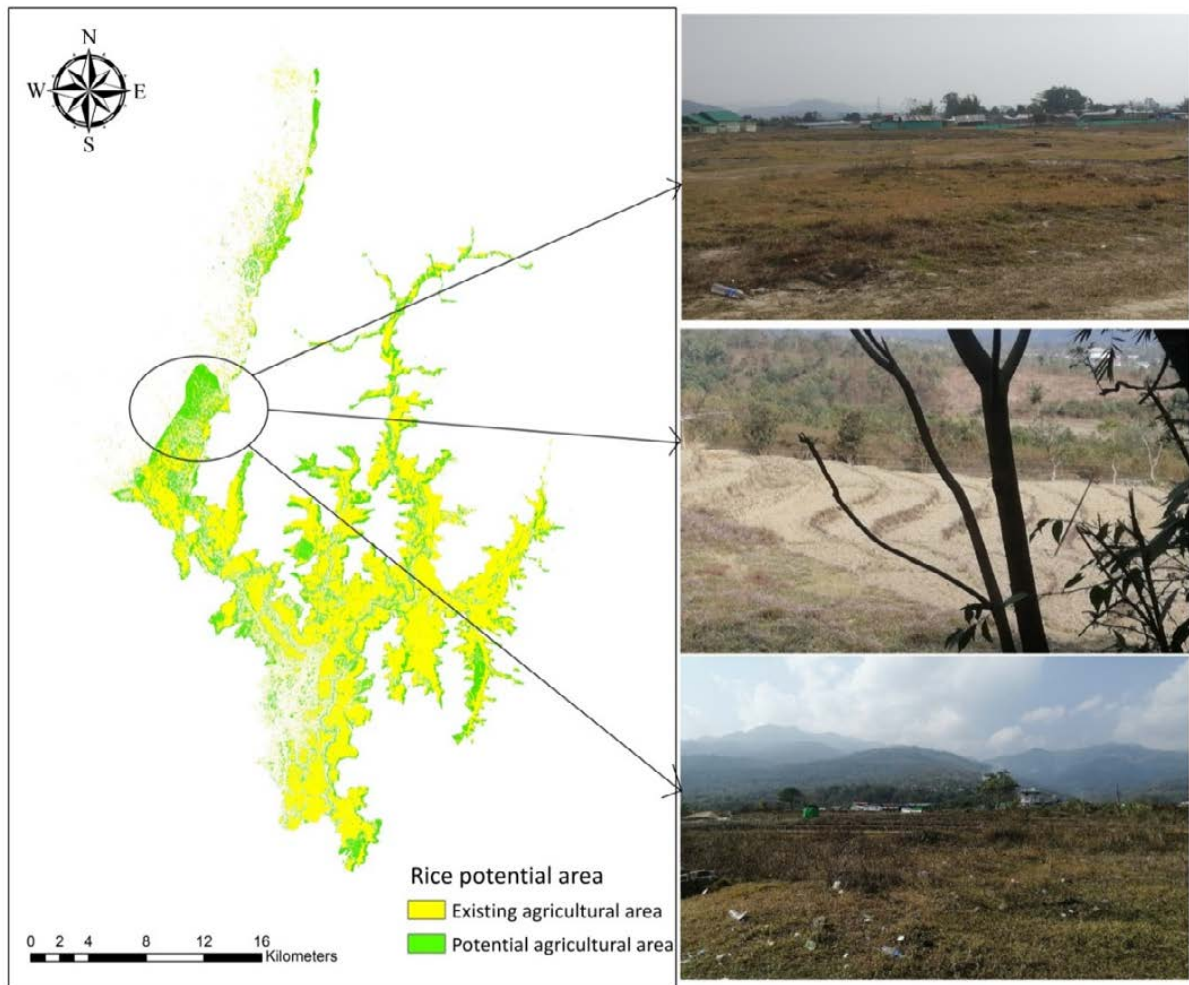


Fig. 5: Potential area for rice cultivation along with the field photographs

60.01 km<sup>2</sup> and 211.63 km<sup>2</sup>. Highly suitable zones were mainly concentrated in the central part of the valley with milder slope, whereas the moderately suitable zones were mainly concentrated near the foot hills with mild/gentle slope. Out of the total area of 271.64 km<sup>2</sup> covered under moderate and highly suitable class, it was observed that the 192.49 km<sup>2</sup> of the area is already under existing agriculture cover. The existing LULC of the catchment covering agriculture class is shown in the Fig. 3. It can be clearly noted that the 79.15 km<sup>2</sup> of the area still has the potential for rice to be cultivated in such zones in the valley. Interestingly it can be noted that the zones with higher suitability is already covered with the existing agriculture cover, whereas the area near the foothills which falls under

moderately suitable class still has the potential to be cultivated since it is not covered under existing agriculture cover. The area under existing agriculture cover and the areas which still have the potential to be cultivated is shown in Fig. 5. There were some major stretches of the land were identified as: 1) near to Kanglatombi, Keithelmanbi, and Kangpokpi and 2) Chanam Sandrok, Langdum. In order to field validate the model result a field survey was carried-out in the Kanglatombi, Keithelmanbi region using handheld Global Positioning System (GPS). From the field survey it was observed that the few stretches of land are being cultivated but the majority portion of the land is still not under the agriculture cover which still has the potential to be cultivated as indicated by

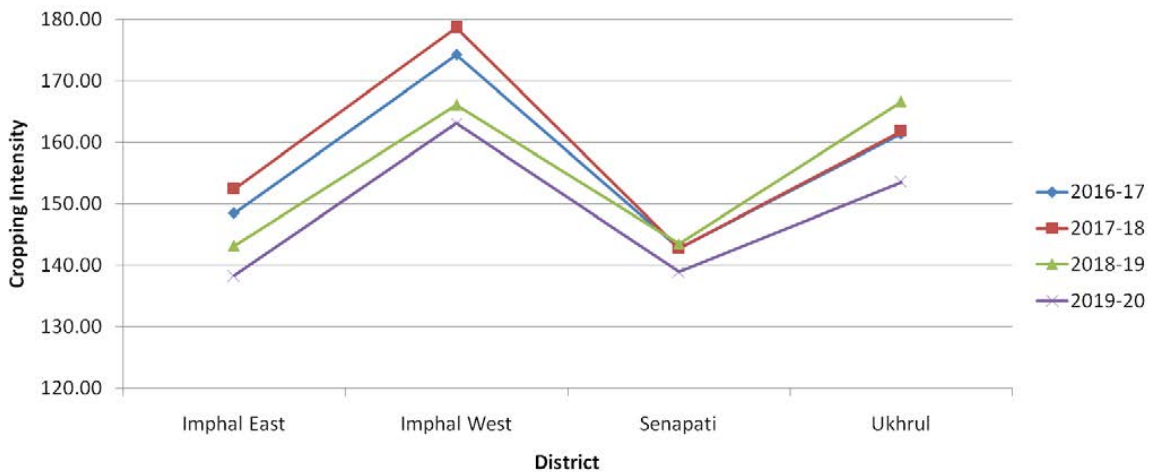


Fig. 6: Cropping intensity of each district lying under Imphal-Iril River catchment (DOA, 2022)

the model result. The potential area which can be cultivated along with the field photographs indicating the small patches of land which is being cultivated and majority of those still left barren is shown in Fig. 5. In this study, the criteria for evaluation were opted by considering the crop requirements based on the local conditions. Factors were selected according to the share knowledge of local experts in agronomist and available relevant literature review. The result of this study provides vital information on the importance of parameters relatively and could be beneficial for the future reference on rice and other crops. This study will further serves as general spatial guideline to the local farmers of the region for their strategy of land use management and crop.

The cropping intensity data was obtained from Directorate of Agriculture (DOA), Govt. Of Manipur at district level for four district namely Senapati, Ukhrul, Imphal West, and Imphal East which intersects the Imphal-Iril River catchment. The trend of cropping intensity between the time periods 2016-2020 is shown in Fig. 6. Since the Senapati and Ukhrul district are under restricted forest belt, the model result was validated by using the datasets of Imphal East and Imphal West districts which covers nearly 95% of the area under rice cultivation in the catchment. The result was validated based on agriculture coverage intensity expressed in terms of percentage. The agriculture area intersected by

Imphal East and Imphal West district under Imphal-Iril River catchment was taken into consideration. The agriculture coverage intensity was computed based on the ratio of total geographical area and the gross cultivable area. The agriculture coverage intensity of Imphal East and Imphal West was computed based on the data obtained from DOA at district level. The computed agricultural coverage intensity was compared with the agriculture coverage intensity simulated by the model under the intersecting zone of Imphal East and Imphal West district. Agriculture area intercepted by Imphal East and Imphal West district under Imphal-Iril River catchment is shown in Fig. 7. The agriculture coverage intensity computed from the field based data obtained from DOA were found to be 71.91% and 84.83% for Imphal East and Imphal West district whereas, the agriculture coverage intensity computed from simulated result of the model for Imphal East and Imphal West under the intersecting zone of Imphal-Iril River catchment were found to be 79.97% and 78.31%, respectively.

## CONCLUSIONS

The rice suitability analysis carried out in this research study clearly indicates the capability of AHP in predicting the suitable zones of rice cultivation when integrated with GIS. The model performance was found to be satisfactory when validation with field based data with model uncertainty lying within

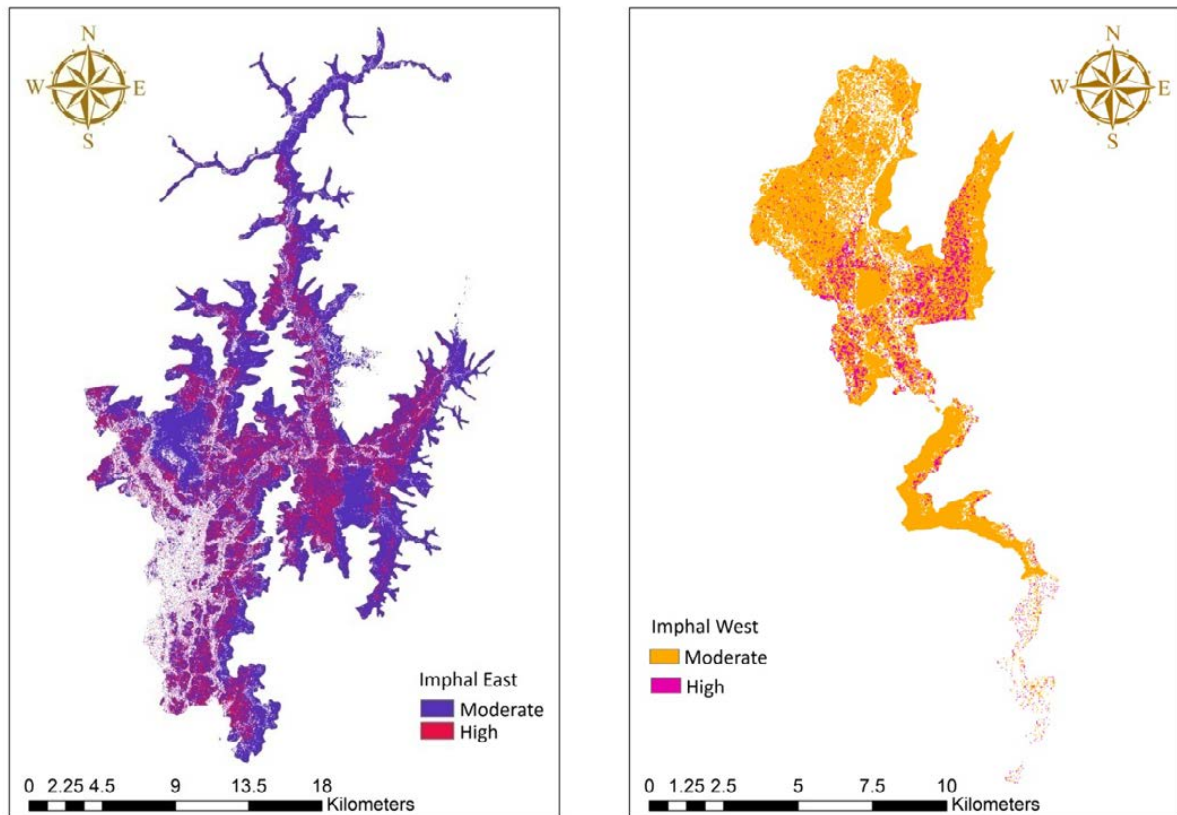


Fig. 7: Agriculture area intercepted by Imphal East and Imphal West district under Imphal-Iril River catchment

10% limit when agriculture coverage intensity of field was compared with the simulated result of Imphal East and Imphal West intersecting within the catchment boundary. The results of this study demonstrate the potential use of Geographical Information System and spatial analyst tools using AHP in identification of potential zones for rice cultivation. It could aid in developing a guide map and suitable database for policy makers which will help in achieving high production of rice in the region. AHP integrated with GIS enables the user to induces the expert based knowledge while carrying out the suitability modelling whereas, the integration with GIS provides the interface to indentifies the zones or its spatial variability since the datas are geotagged. As per the model result of Imphal-Iril River catchment, high and moderate suitability zones were located in the valley region whereas, the marginally suitable to not suitable zones were located in the hilly region. Though the model performance indicates there are

few patches of land were in moderately suitable zone, but practically they cannot be cultivated because of dense deciduous forest cover. In particular, this study clearly indicates the potential zones lying in the foothills which are still not under the agriculture cover. 271.64 km<sup>2</sup> in the valley lies under moderate and highly suitable class of which 70.86% is under agriculture cover, whereas 29.14% of the area lying under moderate suitability class still has the potential to be cultivated. The major section of such potential region can be found in the north-western part of the valley as per the model result. For the purpose of crop management diversification, this study clearly presents the spatial distribution of rice drawn by digitized datasets along with the evaluation of topographic, climatic and soil parameters. The results of this study can provide vital information to the local farmers to select their pattern of cropping. This study results is based on the past climate datasets, and there is a future potential of study which can be done

using future projected General Circulation Model (GCM) datasets to provide the suitability potential of rice in the Imphal-Iril River catchment for the future. As this study is based on soil, topographic and climate parameters, this study paves a way for further study which can be done by incorporating socio-economic factors and irrigation facilities available at regional level which drives the sustainable use of land resources.

## AUTHOR CONTRIBUTIONS

N. Robertson performed the literature review, framework of this study, data analysis and interpretation; prepare the manuscript text and manuscript edition. B. Oinam performed the literature review, model configuration and critical revision of manuscript and supervision.

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## CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

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## ABBREVIATIONS

%	Percentage
AHP	Analytical hierarchy process
°C	Degree Celsius
C	Clay
CI	Consistency index
CL	Clay loam
cm	centimetre
CR	Consistency ratio
DEM	Digital elevation model
DOA	Directorate of Agriculture
Eq	Equation
FAO	Food and Agriculture Organization
GCM	General circulation model
GIS	Geographical information system
GoM	Government of Manipur
GPS	Global positioning system
ICAR	Indian council for agricultural research
Km <sup>2</sup>	Square kilometre
L	Loam
LS	Loamy sand
LULC	Land use land cover
MCE	Multi criteria Evaluation
mm	Millimetre
MODIS	Moderate resolution imaging spectrometer
n	Number of criteria in pairwise comparison matrix
N	Not suitable
NBSS and LUP	National Bureau of Soil Survey and Land Used Planning
OLI	Operational land imager
RI	Random index
S	Sandy
SIL	Silt loam
SL	Sandy loam

S1	Highly suitable
S2	Moderately suitable
S3	Marginally suitable
SCL	Sandy clay loam
SIC	Silt clay
SQL	Structured query language
SRTM	Shuttle radar topography mission
TIRS	Thermal Infra-Red Scanner
TRMM	Tropical rainfall measuring mission
UTM	Universal transverse Mercator
USGS	United States Geological Survey

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**CASE STUDY****Effects of ambient air pollutants on cardiovascular disease hospitalization admission**

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**ABSTRACT**

**BACKGROUND AND OBJECTIVES:** Air pollution is associated with population growth and economic advancement. Severe cardiovascular complications that require extensive medical service are aggravated by air pollutants. This study illustrates the trend and correlation of cardiovascular disease hospital admission with air pollutants in Sabah for the past 9 years (2010–2019). The additional information obtained from this study will be useful to enhance proper environmental management and reduce air pollution in the cities of Sabah.

**METHODS:** Ecological study design was utilized with cardiovascular disease hospital admission and ambient air pollutants in Sabah retrospective data. Data were collected from four districts with established continuous air quality monitoring stations. Collected data were analysed spatially and statistically. Autoregressive integrated moving average modelling was implemented to forecast the cardiovascular disease hospital admission.

**FINDINGS:** Kota Kinabalu recorded the highest hospital admissions for cardiovascular disease, followed by Sandakan, Tawau and Keningau. The cardiovascular disease hospital admission prevalence rate in Kota Kinabalu was 12.45 per 1,000 population, followed by Sandakan, Tawau and Keningau (4.54; 4.18; and 5.88 per 1,000 population) in 2019. The cardiovascular hospital admissions increased in Kota Kinabalu, Sandakan and Tawau. The nitrogen dioxide (<0.04 ppm), carbon monoxide (<9 ppm), ozone (<0.05 ppm) and PM10 (<100 µg/m<sup>3</sup>) gases detected are below the national standard limit levels. In the later years of the series, the ozone and fine particulate gases intensify. Carbon monoxide has the highest positive correlation with cardiovascular disease hospital admission compared to other air pollutants. The autoregressive integrated moving average (0,1,1) with carbon monoxide and ozone as external regressors is the model with minimum Akaike information criterion.

**CONCLUSION:** The carbon monoxide concentration in ambient air illustrates a potential risk for the increasing cardiovascular disease hospital admission number in Sabah. The study findings provide evidence-based source for the healthcare management team, policymakers, and community to sustain clean and safe ambient air.

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## INTRODUCTION

Cardiovascular disease (CVD) is the prime cause of death in man, which accounts for 31% death worldwide (CVD-WHO, 2020). In Europe, CVD death was established to be twice that of cancer. The mortality rate diverges according to countries. Russia and Ukraine recorded immense mortality rates among the older group. Meanwhile, in France, most younger generations are diagnosed with CVD (Nichols *et al.*, 2014). Almost half of the cardiovascular cases reported are from populated Asian countries (Soenarta *et al.*, 2020). Cardiovascular disease prevalence is tripling in India among the younger generation (Chauhan *et al.*, 2013). Cardiovascular disease had been a prominent cause of death among males for the past 13 years in Malaysia (DOSM, 2019). Cardiovascular diseases were related to the high number of Daily Adjusted Life Years (DALYs) loss (2.5 million DALYs) (Plass *et al.*, 2014). In 2016, almost 7 million premature deaths were associated with air pollution, and low- and middle-income countries contributed to 80% of these deaths. Various adverse health outcomes such as respiratory infections, heart disease, stroke, and lung cancer are known to be related to air pollution (AQPAHO, 2020). Carbon monoxide (CO) is high in urban areas because of ongoing human activities and transportation. Inhaled CO binds with haemoglobin in the blood which triggers carbon monoxide-induced cardiac incoherence (Meyer *et al.*, 2011). Every 10 microgram per cubic meter ( $\mu\text{g}/\text{m}^3$ ) increase in fine particulate matter ( $\text{PM}_{2.5}$ ) in the long term may increase cardiovascular mortality risk by 11%. Meanwhile, short-term exposure to nitrogen oxide ( $\text{NO}_2$ ) is also associated with cardiovascular effect development. Air pollution enhances endothelial dysfunction and platelet activation favoring thrombus formation (Bourdrel *et al.*, 2017). Up to 2 billion individuals suffer from chronic CVD sequelae. CVD accounts for expenditures of nearly United State Dollar (USD) 317 per year. The treatment for cardiovascular disease accounts for USD 1 for every USD 6 paid to the healthcare system. Even health care facilities will be helpless to cope with the healthcare air pollution and climate change consequences if this condition persists (Richardson *et al.*, 2014). Air pollutants are a serious public health threat because of the large-scale environmental risk vulnerability towards the population. Air pollution has increased along with the population growth and economic advancement over the decades (Brown, 2008). Air pollution emissions

depend on industrial expansion, technology utilization, fuel consumption increase, vehicle emission, and burning. A total of 70 million tons of pollution were liberated into the atmosphere by the United States in 2019 according to the Environment Protection Agency (EPA), potentially creating an accumulation of particles and acids (USEPA, 2016). Low- and middle-income countries experience immense urban air pollution particularly in the Eastern Mediterranean, Southeast Asia, and Western-Pacific regions, in which annual mean residue is 10 times higher than the World Health Organization standard level. Asian and Pacific countries are the most disturbed by air pollution whereby 90% of the population is exposed to air particles that potentially lead to adverse health effects (WHO, 2016). In addition, climate change can accelerate ambient air pollutant levels causing serious health consequences (Forsberg *et al.*, 2012). The autoregressive integrated moving average (ARIMA) model was first established in 1976 to predict infectious disease and applied as an early warning alarm for control and prevention measures (Luz *et al.*, 2008). The ARIMA model is shown to have been highly predictive on medical condition and precision for short term exposure (Yi *et al.*, 2014). This model has also been implemented in predicting environmental parameters, such as air pollutants (Konovalov *et al.*, 2009). A Madrid study evaluated an intervention program in the city by forecasting the air pollutant level (Pedro *et al.*, 2017). Furthermore, researchers advanced the ARIMA application to investigate the associations between environmental factors and health effects (Imai *et al.*, 2015). Disease trends can be described and forecasted with the environmental variable by implementing the ARIMA model (Sharafi *et al.*, 2017). This study aimed to describe the cardiovascular disease hospital admission trend and correlation with air pollutants in four districts (Kota Kinabalu, Sandakan, Tawau, and Keningau) and develop a forecasting model for cardiovascular disease hospital admission. The data from respective districts were collected from 2010 to 2019.

## MATERIALS AND METHODS

This ecological study design reviews retrospective data on CVD hospital admission and air-borne environmental variables for the past 9 years (2010–2019), comparing four districts in Sabah. The study was carried out in Kota Kinabalu, Sandakan, Tawau, and Keningau, which have established continuous

Table 1: Standard limit for air pollutants

Air pollutants	DOE standard limit	
	$\mu\text{g}/\text{m}^3$	ppm
$\text{NO}_2$	280 (1 h)	0.14 (1 h)
	70 (24 hs)	0.04 (24 hs)
$\text{O}_3$	180 (1 h)	0.09 (1 h)
	100 (8 hs)	0.05 (8 hs)
$\text{CO}$	30 (1 h)	25 (1 h)
	10 (8 hs)	9 (8 hs)
$\text{PM}_{10}$	100 (24 hs)	-
	40 (1 y)	-

Table 2: Hospital admission for cardiovascular disease in Sabah 2010–2019

District	Mean (SD)									
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Kota Kinabalu	6(3)	8(4)	9(5)	12(5)	13(6)	13(6)	12(5)	14(6)	16(6)	16(6)
Sandakan	3(2)	4(2)	4(2)	3(2)	4(2)	3(2)	4(2)	5(2)	5(2)	5(2)
Tawau	3(2)	4(2)	4(2)	4(2)	4(2)	4(2)	4(2)	5(3)	5(2)	5(2)
Keningau	2(1)	2(1)	3(2)	3(2)	3(2)	2(1)	3(1)	3(2)	3(2)	3(2)

SD = Standard deviation

air quality monitoring (CAQM) stations for air pollutants ( $\text{NO}_2$ ,  $\text{O}_3$ ,  $\text{CO}$ , and  $\text{PM}_{10}$ ). The number of hospital admission for CVD was extracted according to WHO ICD classification (WHO ICD code: I00-I99) from Malaysia Health Informatic Centre. Air quality data were retrieved from the Malaysia Department of Environment from the stations located adjacent to the study hospitals. The mean daily ambient concentrations of particulate matter less than 10 microns ( $\text{PM}_{10}$ ) in  $\mu\text{g}/\text{m}^3$ , nitrogen dioxide ( $\text{NO}_2$ ) in part per million (ppm), ozone ( $\text{O}_3$ ) in ppm and  $\text{CO}$  in ppm were collected. The obtained data were re-coded into numerical orders in day, month, year (DD.MM.YYYY); district;  $\text{CO}$ ;  $\text{NO}_2$ ;  $\text{O}_3$ ;  $\text{PM}_{10}$ ; and CVD hospital admission. A dataset that fulfils statistical and modelling analysis criteria was established to subsequently merge these data. Missing data were imputed through last observation carried forward method. The data was prepared in daily and monthly trends. Descriptive analysis used the IBM Statistical Package for Social Sciences (SPSS) version 26. The result was compared with national air pollutants standard limits (Table 1) (MDE, 2020). Standard limit set was below 0.04 ppm (<0.04 ppm) for  $\text{NO}_2$ ,  $\text{O}_3$  (<0.05 ppm),  $\text{CO}$  (<9 ppm), and  $\text{PM}_{10}$  (<100  $\mu\text{g}/\text{m}^3$ ). R program software version 4.1 was applied for advanced Pearson correlation coefficient statistical analysis, time series analysis, and ARIMA.

model has been widely applied in medical data to identify the data's cyclic pattern and time series features. Subsequently, the estimated model was established by adjusting the algorithm and reducing the prediction error (Huang *et al.*, 2020). Data were prepared and cleaned to be extracted into the software during the initial phase of analysis. The trend and seasonality of the data were described. Then, the potential model is estimated by comparing Akaike Information Criteria (AIC), Ljung-box test, forecast error (Root Mean Square Error (RMSE), Mean Absolute Percentage Error (MAPE) and Mean Absolute Error (MAE)) and regressors. Finally, the parsimonious model was used to estimate the CVD hospital admission number for the next 12 months (Sato, 2013). Several packages were installed to run the analysis including tidyverse, xts, and forecast package. The tidyverse and xts packages were used to clean data and arrange it in daily trends. Meanwhile, the forecast package was applied to illustrated time series analysis and ARIMA.

## RESULTS AND DISCUSSION

### Cardiovascular disease hospital admission in Sabah 2010–2019

Kota Kinabalu recorded the highest hospital admission CVD number compared to other districts followed by Sandakan, Tawau, and Keningau (Table 2).

The yearly average hospital admission was ascending rapidly over the years. Sandakan and Tawau hospitals have had similar admissions for the past 9 years. Meanwhile, a Keningau hospital has the least admission number and was continuous. The higher prevalence CVD hospital admission rate was in Kota Kinabalu (12.45 per 1,000 population), followed by Keningau (5.88 per 1,000 population), Sandakan (4.54 per 1,000 population), and Tawau (4.18 per 1,000 population) for 2019.

*Time series analysis of cardiovascular disease hospital admission and air pollutants in Sabah 2010–2019*

All districts experienced a steady upsurging

CVD hospital admission trend over the years. In the interim, air pollutants recorded a fluctuating pattern (Fig. 1a-d). However, the mean air pollutants recorded over the years was below the national standard limit levels (Table 3). Nevertheless, O<sub>3</sub> and PM<sub>10</sub> gases intensified in the series' later years, particularly in Kota Kinabalu and Tawau. The number of hospital admission increased drastically in Kota Kinabalu and Tawau during the decomposition of additive time series analysis. Meanwhile, Sandakan started to increase during the middle years of the series (Fig. 2). European countries outlined a similar increasing CVD admission trend as observed in this study. Despite admission increasing steadily, death

Table 3: Air pollutants in Sabah 2010–2019

District	Mean (SD)									
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Kota Kinabalu										
NO <sub>2</sub>	0.0129	0.0150	0.0165	0.0155	0.0161	0.0151	0.0142	0.0138	0.0115	0.0079
<0.04 ppm	(0.0050)	(0.0047)	(0.0044)	(0.0045)	(0.0055)	(0.0062)	(0.0051)	(0.0091)	(0.0081)	(0.0049)
O <sub>3</sub>	0.0244	0.0248	0.0280	0.0211	0.0269	0.0364	0.0323	0.0308	0.0301	0.0311
<0.05 ppm	(0.0078)	(0.0064)	(0.0072)	(0.0093)	(0.0086)	(0.0099)	(0.0092)	(0.0098)	(0.0065)	(0.0099)
CO	0.5834	0.6621	0.6565	0.6223	0.6018	0.6454	0.5930	0.8882	0.7602	0.6050
<9 ppm	(0.1630)	(0.1728)	(0.1778)	(0.2054)	(0.1645)	(0.2488)	(0.1895)	(0.3492)	(0.3472)	(0.2399)
PM <sub>10</sub>	39.383	37.478	38.474	41.690	38.353	45.019	43.148	40.3190	57.079	57.058
<100 µg/m <sup>3</sup>	(10.779)	(9.3347)	(9.7500)	(13.654)	(8.0693)	(13.158)	(11.281)	(18.921)	(55.748)	(135.66)
Sandakan										
NO <sub>2</sub>	0.0125	0.0134	0.0137	0.0126	0.0119	0.0111	0.0100	0.0112	0.0108	0.0108
<0.04 ppm	(0.0034)	(0.0043)	(0.0038)	(0.0038)	(0.0038)	(0.0041)	(0.0031)	(0.0032)	(0.0030)	(0.0034)
O <sub>3</sub>	0.0235	0.0270	0.0286	0.0270	0.0283	0.0284	0.0295	0.0259	0.0246	0.0266
<0.05 ppm	(0.0067)	(0.0085)	(0.0083)	(0.0085)	(0.0070)	(0.0063)	(0.0066)	(0.0066)	(0.0057)	(0.0065)
CO	0.4720	0.5119	0.4790	0.4798	0.4850	0.5511	0.4984	0.7175	0.7427	0.7421
<9 ppm	(0.1757)	(0.1522)	(0.1503)	(0.1707)	(0.1500)	(0.2221)	(0.1277)	(0.2109)	(0.1760)	(0.1807)
PM <sub>10</sub>	30.518	36.706	35.585	39.079	35.118	37.208	25.928	41.978	34.339	33.556
<100 µg/m <sup>3</sup>	(7.3461)	(7.0990)	(6.5003)	(6.8184)	(6.8660)	(13.692)	(6.0272)	(15.324)	(11.112)	(15.720)
Tawau										
NO <sub>2</sub>	0.0128	0.0133	0.0151	0.0143	0.0145	0.0147	0.0130	0.0137	0.0146	0.0140
<0.04 ppm	(0.0033)	(0.0034)	(0.0057)	(0.0035)	(0.0035)	(0.0042)	(0.0032)	(0.0038)	(0.0039)	(0.0039)
O <sub>3</sub>	0.0252	0.0267	0.0267	0.0265	0.0267	0.0283	0.0258	0.0249	0.0246	0.0272
<0.05 ppm	(0.0096)	(0.0075)	(0.0073)	(0.0075)	(0.0089)	(0.0090)	(0.0077)	(0.0073)	(0.0063)	(0.0077)
CO	0.6456	0.5790	0.5885	0.6166	0.7352	0.7929	0.6275	0.9986	1.0281	1.0027
<9 ppm	(0.2282)	(0.1639)	(0.2046)	(0.2620)	(0.2428)	(0.3806)	(0.1534)	(0.3160)	(0.1845)	(0.2150)
PM <sub>10</sub>	41.505	41.011	39.281	36.740	33.688	43.324	31.883	37.096	32.560	32.219
<100 µg/m <sup>3</sup>	(5.8810)	(8.6202)	(8.4291)	(6.3920)	(9.7958)	(32.468)	(6.8326)	(10.987)	(11.550)	(17.156)
Keningau										
NO <sub>2</sub>	0.0071	0.0096	0.0087	0.0092	0.0081	0.0080	0.0090	0.0080	0.0086	0.0089
<0.04 ppm	(0.0031)	(0.0039)	(0.0037)	(0.0043)	(0.0038)	(0.0033)	(0.0038)	(0.0034)	(0.0040)	(0.0040)
O <sub>3</sub>	0.0204	0.0233	0.0230	0.0209	0.0226	0.0233	0.0271	0.0219	0.0238	0.0253
<0.05 ppm	(0.0061)	(0.0062)	(0.0064)	(0.0053)	(0.0081)	(0.0063)	(0.0082)	(0.0063)	(0.0058)	(0.0065)
CO	0.4202	0.4170	0.5422	0.4850	0.4805	0.4667	0.4889	0.6319	0.8523	0.8702
<9 ppm	(0.1478)	(0.1679)	(0.2140)	(0.1891)	(0.1494)	(0.1751)	(0.1766)	(0.2187)	(0.2248)	(0.2102)
PM <sub>10</sub>	36.248	35.674	35.660	35.412	35.959	36.944	32.674	38.660	42.212	43.653
<100 µg/m <sup>3</sup>	(11.252)	(10.691)	(10.957)	(14.232)	(9.5845)	(14.733)	(10.995)	(17.095)	(18.845)	(22.021)

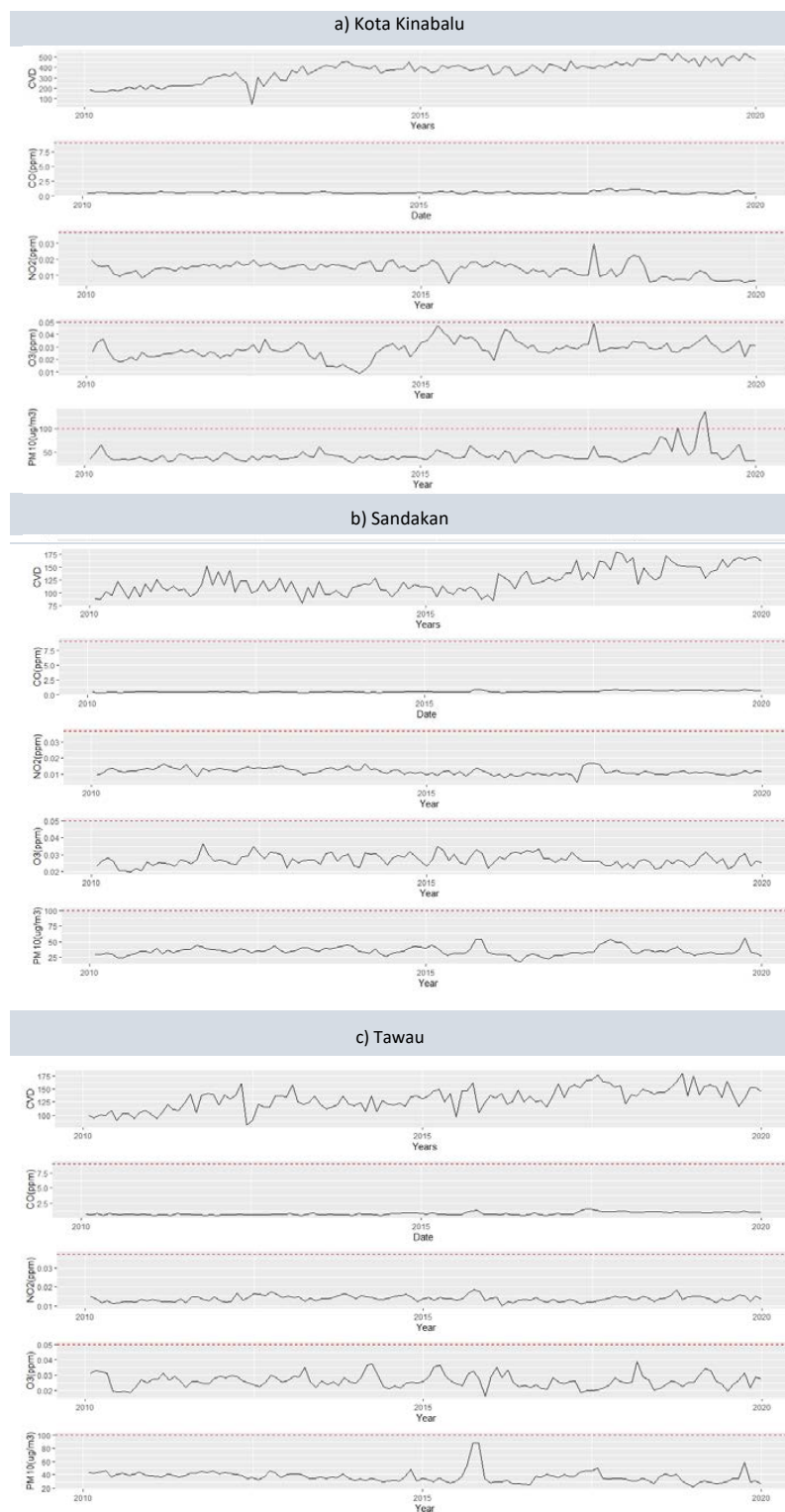
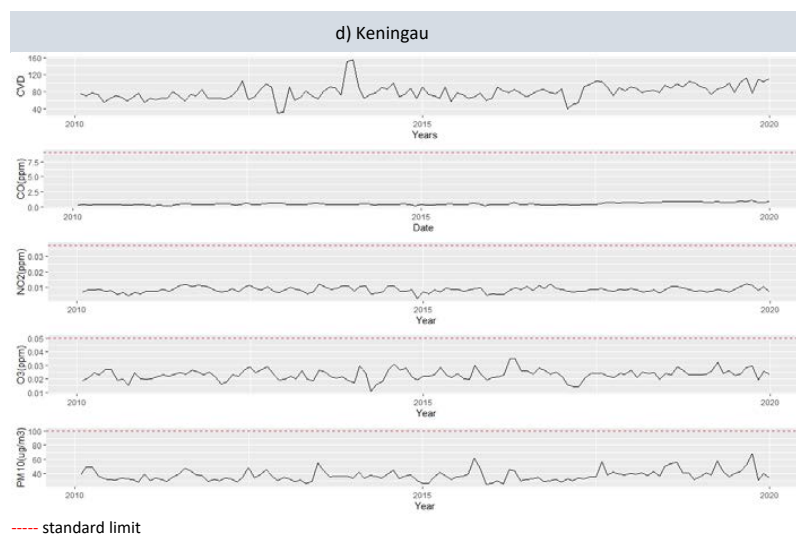


Fig. 1: Time series analysis of hospital admission for cardiovascular and air pollutants in Kota Kinabalu 2010–2019



Continued Fig. 1: Time series analysis of hospital admission for cardiovascular and air pollutants in Kota Kinabalu 2010–2019

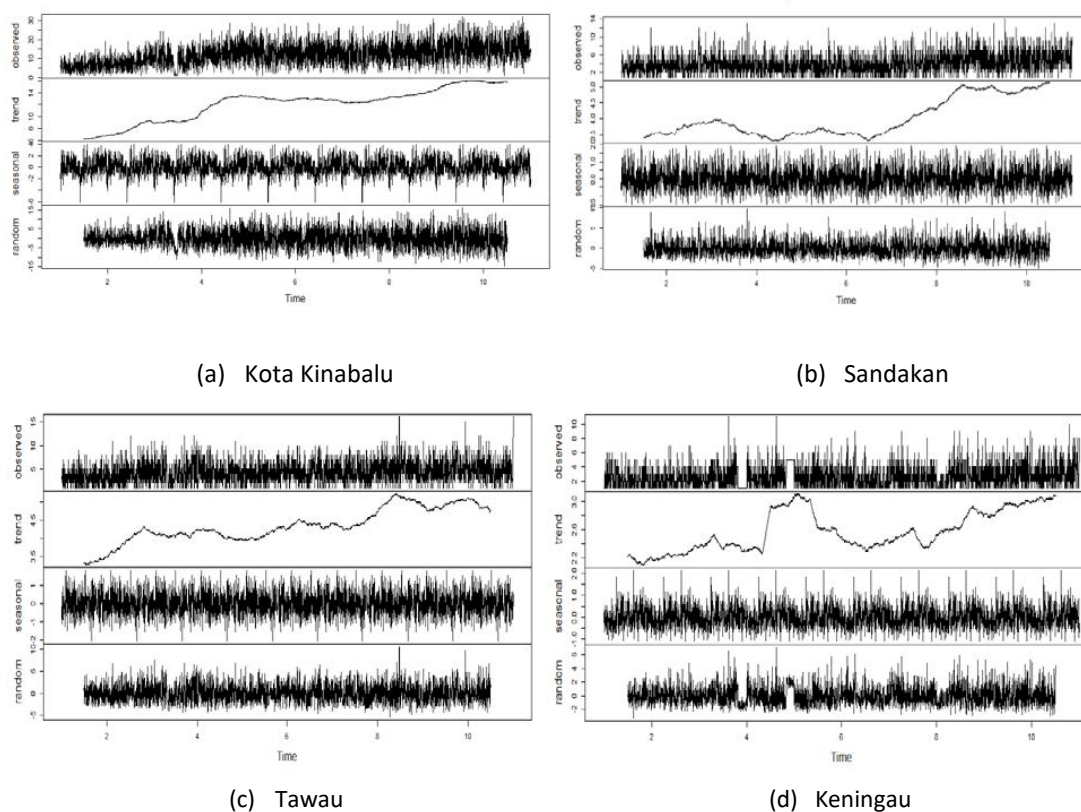


Fig. 2: Decomposition additive time series of CVD hospital admission

rates decreased from 1980 until 2013 (Bhatnagar *et al.*, 2016). A Chinese study 4 years ago demonstrated a spatially clustered pattern with decreasing CVD hospital admission number which is in contrast with the present findings (Amsalu *et al.*, 2021). Seasonal countries had some variation. A higher CVD admissions number and death were seen during

winter. CVD deaths were related to acute myocardial infarction, acute left ventricular failure and unstable angina (Khan *et al.*, 2014). Nevertheless, concurrent to the current findings, cases of CVD deaths in Malaysia rose from 14.4% (2017) to 15.9% (2018) in urban and 12.7% to 15.0% in rural areas (DOSM, 2019). Air pollutions study results show a disparity

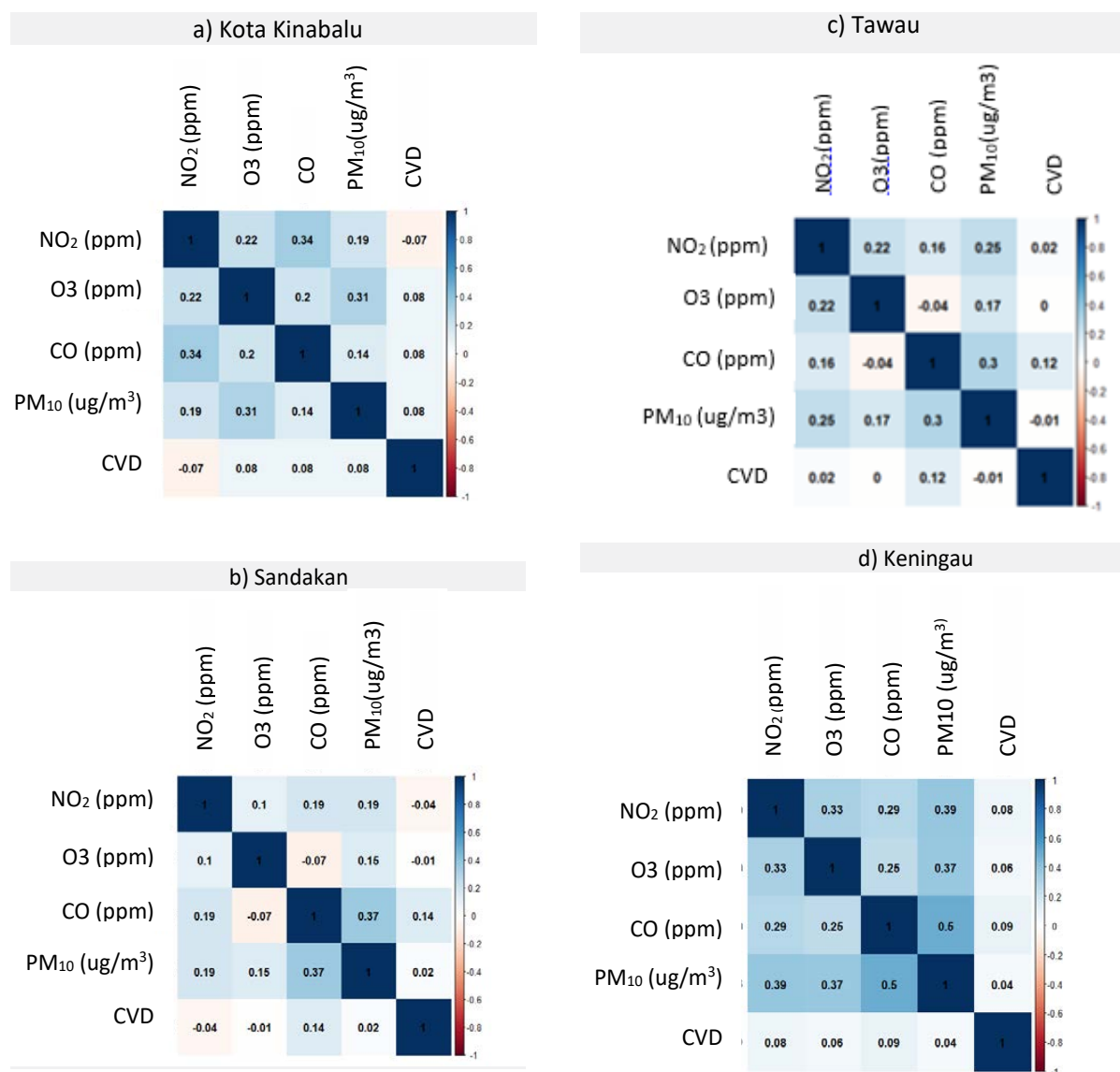


Fig. 3: Correlation coefficient between the air pollutants and cardiovascular hospital admission in Sabah 2010–2019 (a)Kota Kinabalu (b) Sandakan (c)Tawau (d)Keningau

in the findings in the present study. A study in the United Kingdom reported  $PM_{10}$  and  $O_3$  were consistently above the WHO limit. Hence,  $O_3$  become a major concern for premature death (Sicard *et al.*, 2021). On the other hand, air pollutants expects for  $O_3$  surged in China by 9% for a 4-year period (2015–2019). The  $SO_2$  reading dwindled by 36–60%, while other pollutants abated within a 3–33% range (Zhou *et al.*, 2020). A time series study in Lahore reported an ascending air pollutants trend ( $PM_{10}$ ,  $PM_{2.5}$ ,  $NO$ ,  $NO_2$ ,  $O_3$  and  $CO$ ) (Bhatti *et al.*, 2021). In Malaysia, long-term temporal dynamic air pollutant data (1997–2015) from 20 monitoring stations reported large coefficient variations for  $PM_{10}$ . The central region of Malaysia is identified to have an immense air pollutants concentration compared to northern, southern, eastern, and Borneo. Stations in Borneo (Kuching, Bintulu, Miri, and Kota Kinabalu) reported a lower reading compared to stations in peninsular Malaysia. In the current study, the collateral trend was observed for  $PM_{10}$  before 2016. However,  $PM_{10}$  parameters increased in 2017 and endured a plateau trend until 2019 (Sentian *et al.*, 2019). Subsequent monitoring from the current study illustrated a downward  $NO_2$  trend and rising  $CO$  numbers parameters. A distinct forecast study from 1997 until 2016 in the eastern peninsular Malaysia part (Pahang, Terengganu, and Kelantan) illustrated

a congruent  $CO$  trend, but the  $NO_2$  parameter was contrary to current finding (Ibrahim *et al.*, 2009).

#### Correlation coefficient between the air pollutants and cardiovascular hospital admission in Sabah, 2010–2019

Keningau district illustrated a positive correlation towards all air pollutants (Fig. 3).  $CO$  demonstrated a preeminent correlation with CVD admission followed by  $NO_2$ ,  $O_3$ , and  $PM_{10}$ . Kota Kinabalu displayed three air pollutants ( $O_3$ ,  $CO$  and  $PM_{10}$ ) with a low positive correlation with CVD admission. In Sandakan ( $CO$  and  $PM_{10}$ ) and Tawau ( $CO$  and  $NO_2$ ), two air pollutants positively correlated with CVD admission. In all districts,  $CO$  had the highest CVD admission correlation value compared to other air pollutants. The risk of CVD hospital admission attributed to air pollutants highlighted worldwide. A study in Urmia illustrated a higher correlation between  $CO$  concentration and CVD admission incidence. In addition, the study highlighted admission case increase for every  $10 \mu g/m^3$  (Sokoty *et al.*, 2021). Similarly, a study in Beijing highlighted that exposure to ambient  $CO$  increases the risk of hospital admission, especially coronary heart disease (CHD) (Li *et al.*, 2018). Another local study in Kuala Lumpur reported CVD admission increase with the  $NO_2$  concentration (Sofwan *et al.*, 2021).

Table 4: ARIMA model for cardiovascular hospital admission in Sabah 2010–2019 with air pollutants as the regressor

ARIMA model	AIC	Ljung-box test		Forecast error		
		Q	p-value	RMSE	MAPE	MAE
Kota Kinabalu						
<sup>b</sup> Model 1(0,1,1)	1240.069	5.4423	0.606	42.4823	12.53094	30.04068
<sup>c</sup> Model 2(0,1,1)	1240.711	5.4329	0.6073	42.61948	12.70077	30.57553
<sup>a</sup> Model 3(0,1,1)	1241.596	5.5184	0.701	43.16686	12.87206	30.90907
Sandakan						
<sup>e</sup> Model 1(0,1,1)	987.6061	13.529	0.09489	14.83993	9.353686	11.3033
<sup>f</sup> Model 2(0,1,1)	987.6088	13.564	0.09385	14.84036	9.352232	11.30254
<sup>g</sup> Model 3(0,1,1)	987.612	13.55	0.09426	14.84019	9.355505	11.30518
Tawau						
<sup>h</sup> Model 1(0,1,1)	992.442	8.3476	0.4003	15.07247	9.03198	11.43466
<sup>e</sup> Model 2(0,1,1)	992.5319	8.4144	0.3941	15.0782	9.040969	11.446
<sup>f</sup> Model 3(0,1,1)	992.5907	8.4477	0.391	15.08196	9.042505	11.44757
Keningau						
<sup>c</sup> Model 1(0,1,2)	1004.459	3.872	0.7944	15.74047	15.26077	11.193
<sup>a</sup> Model 2(0,1,2)	1005.43	2.9679	0.9364	15.95171	15.43113	11.2615
<sup>h</sup> Model 3(0,1,2)	1005.881	3.9177	0.7892	15.83803	15.10974	11.10421

AIC = Akaike Information Criteria; Q = Q statistic; RMSE = Root mean square error; MAPE = Mean absolute percentage error; MAE = Mean absolute error.

<sup>a</sup> without regressor; <sup>b</sup> $O_3$ ; <sup>c</sup> $NO_2$ ; <sup>d</sup> $PM_{10}$ ; <sup>e</sup> $CO$ ; <sup>f</sup> $CO$  and  $NO_2$ ; <sup>g</sup> $CO$  and  $O_3$ ; <sup>h</sup> $O_3$  and  $NO_2$ .

Short term  $\text{NO}_2$ ,  $\text{SO}_2$ , and CO exposure escalated the hospital admission risk at different lag and gender in Tehran (Motesaddi *et al.*, 2021). Another interesting study reported that air pollutants were associated with higher CVD hospital visits compared to COPD (chronic obstructive pulmonary disease). The hospital CVD visits was predominant among older adults (>65 years old) and females (Yang *et al.*, 2021). Seasonal countries like Mongolia reported a significant correlation between cardiovascular diseases and majority of air pollutants ( $\text{PM}_{2.5}$ ,  $\text{PM}_{10}$ ,  $\text{NO}_2$ ,  $\text{SO}_2$ , CO, and O<sub>3</sub>) (Enkhjargal *et al.*, 2020). During the warm season, CVD admission surges after an increase in  $\text{PM}_{2.5}$  (Lee *et al.*, 2021). Nevertheless, a study involving three hospitals in Isfahan, Iran, demonstrated a positive association between air

pollutants and myocardial infarction, but it was not statistically significant (Davoodabadi *et al.*, 2019). A study in Switzerland showed no correlation between  $\text{PM}_{10}$  and O<sub>3</sub> with CHD. Only  $\text{SO}_2$  and  $\text{NO}_2$  positively correlated with CHD admission rates (Filippini *et al.*, 2019).

#### ARIMA and forecasting cardiovascular hospital admission in Sabah

ARIMA with and without air pollutants as regressor was performed to establish the best model with minimum AIC (Akaike Information Centre) (Table 4). The R program forecast package applied the auto ARIMA function during analysis. Identical model ARIMA was shared by three districts (0,1,1); however, air pollutants in the model vary.

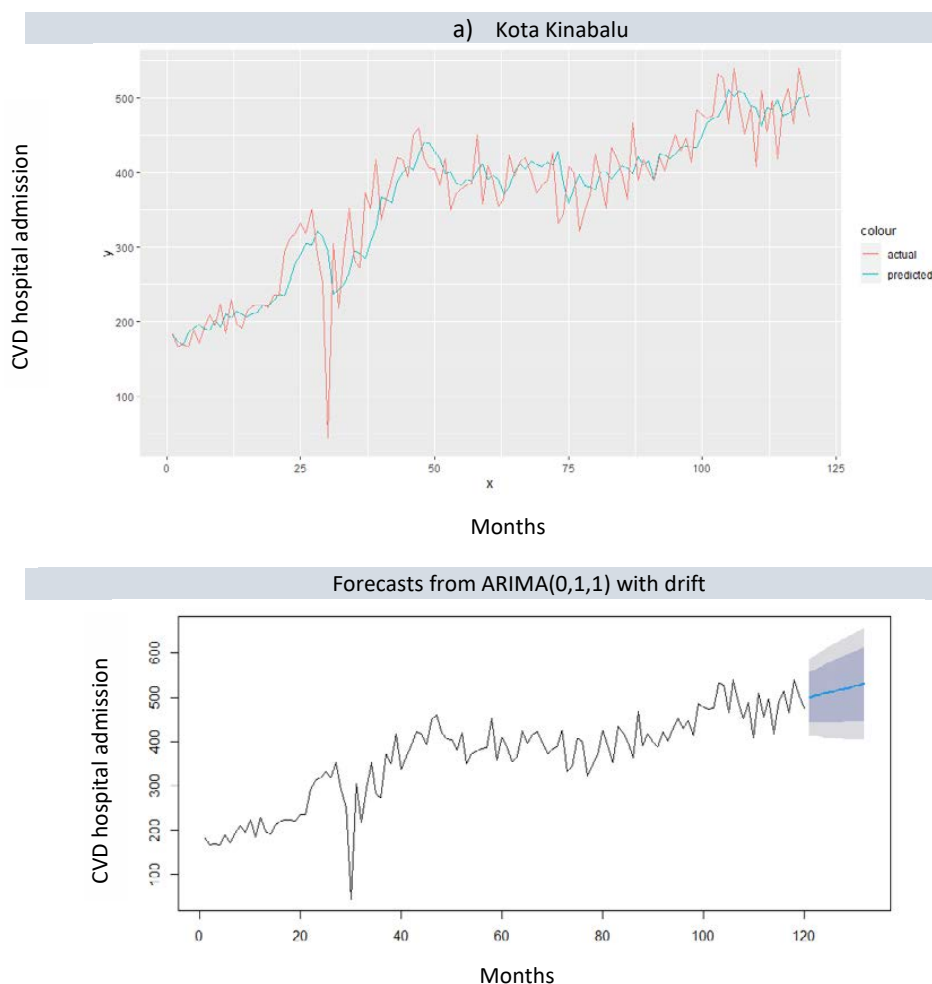
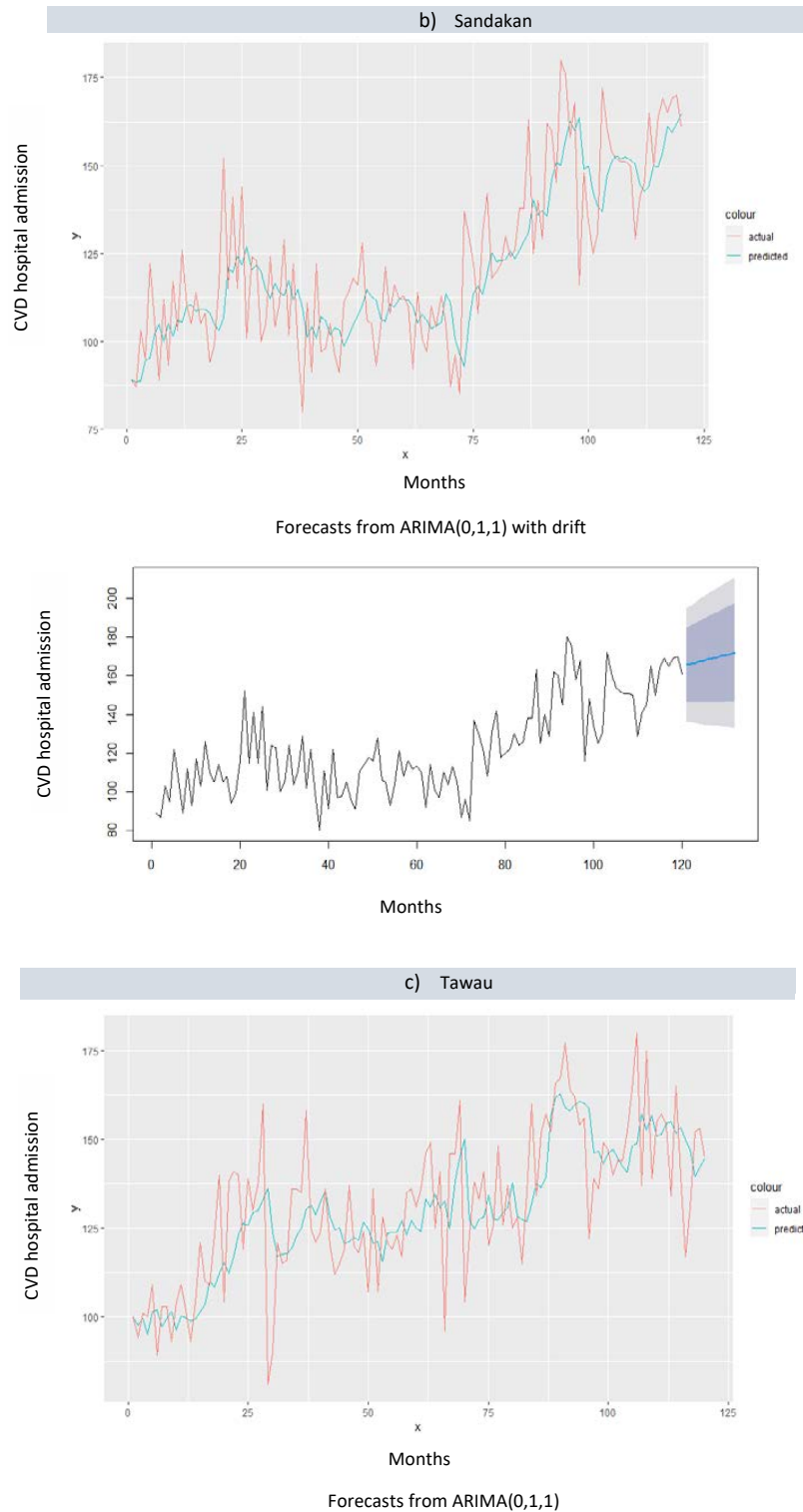
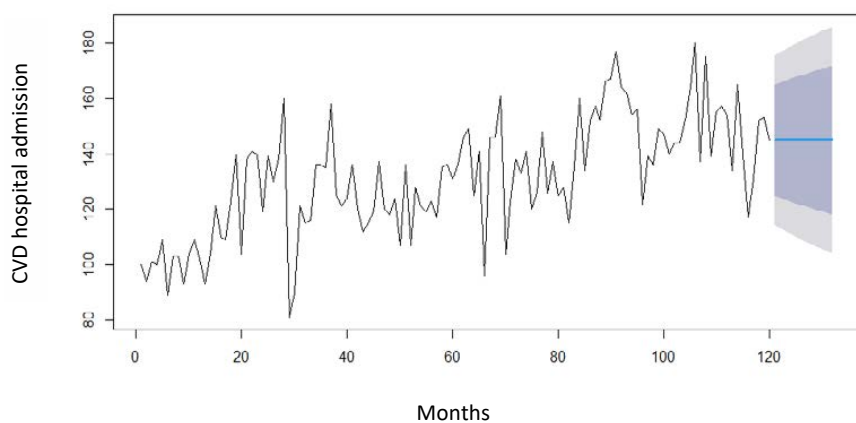


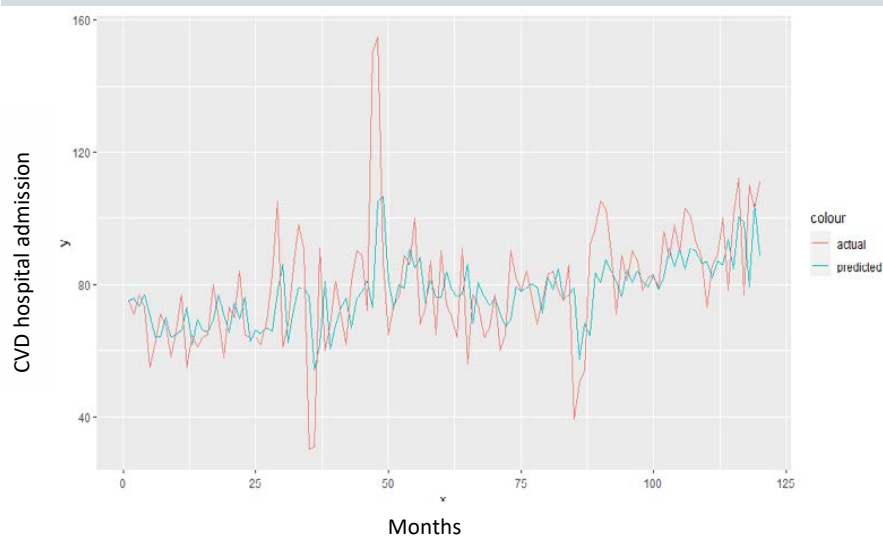
Fig. 4: Prediction forecast of cardiovascular hospital admission in Sabah with air pollutants as regressor in ARIMA



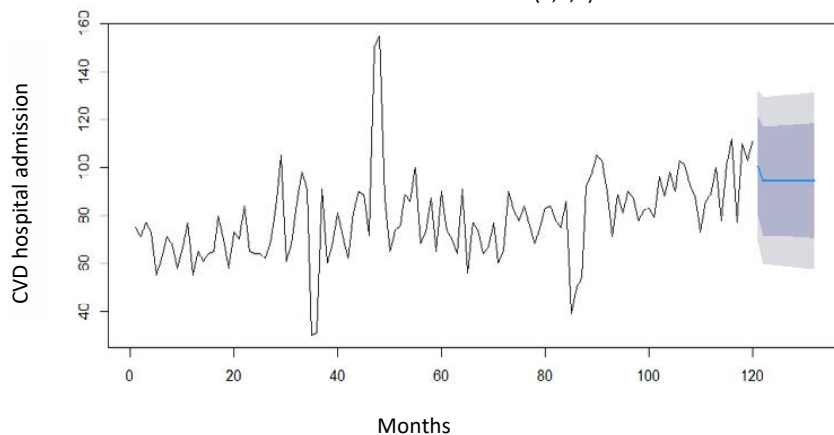
Continued Fig. 4: Prediction forecast of cardiovascular hospital admission in Sabah with air pollutants as regressor in ARIMA



d) Keningau



Forecasts from ARIMA(0,1,2)



Continued Fig. 4: Prediction forecast of cardiovascular hospital admission in Sabah with air pollutants as regressor in ARIMA

Kota Kinabalu (O<sub>3</sub>) and Sandakan (CO) resulted single air pollutant to be relevant in the model. Meanwhile, Tawau has two air pollutants (CO and O<sub>3</sub>) as relevant regressors in the model. Analysis with Keningau data resulted in ARIMA (0,1,2) model with NO<sub>2</sub> as the single pollutant regressor. The *p*-value was more than 0.05 and the null hypothesis was not rejected in the Ljung-Box test. This means the established model does not show any lack of fit. CVD hospital admission forecasting was conducted with the established ARIMA model. Kota Kinabalu and Sandakan showed an increased trend of admission. Meanwhile, Tawau and Keningau noted minimal changes in fluctuation during the prediction (Fig. 4). A limited number of studies are available to illustrate the ARIMA application model to find the relation between CVD hospital admission and air pollutants. A study in Spain projected a similar finding to the current study with the ARIMA model (0,1,1). However, only the Keningau district gave a disparate result ARIMA model (0,1,2). The present study demonstrated three air pollutants (CO, O<sub>3</sub> and NO<sub>2</sub>) might be relevant in the model compared to two air pollutants (SO and NO<sub>2</sub>) (Artola et al., 2019). Another study in Turkey proposed a contrary Seasonal ARIMA model of (2,1,2) (1,0,0)<sub>12</sub>, which includes a seasonal CVD admission factor and is estimated to increase mainly in April. During the winter season, healthcare facilities may experience a double burden of hospital CVD admission and respiratory diseases (Mercan et al., 2019). Other weather and social variable are shown to affect cardiovascular disease. This was not included in the current study. A study in Iran highlighted temperature, sunshine, and religious mourning events increase the risk of acute myocardial infraction (AMI). The best predicted model obtained was from the autoregressive moving average (ARMA) model (5,5). (Sharif Nia et al., 2021). Unlike the current study, several studies applied machine learning techniques to predict cardiovascular hospital admission considering air pollutants. LightGBM model with meteorological and air pollutants reading significantly contributed to the CVD hospital admission accuracy in Chengdu, China (Qiu et al., 2020). A nonlinear ANN model with four hidden layers and 49 neurons was described as the best model for PM, NO<sub>2</sub>, O<sub>3</sub>, and SO<sub>2</sub>. The correlation coefficient ranges from 0.78–0.83, and can predict cardiovascular rate in 5 years' time

data series (Jalili et al., 2021). Another local study in Malaysia proposed enhanced long short-term memory (ELSTM) model to accurately predict the cardiorespiratory hospitalization rate based on air pollution (Usmani et al., 2021).

## CONCLUSION

This study reported a higher CVD hospital admission prevalence in Kota Kinabalu compared to other districts. Nevertheless, decompressive time series analysis illustrated an increasing hospital admission trend over a 9-year period in all the districts. The CO concentration in ambient air was identified as a potential risk for the increasing number of CVD hospital admission in Sabah from a correlation coefficient analysis. Findings proved that air pollution is strongly corrected with CVD hospital admission. A forecast model was developed to determine CVD hospital admission attributed to air pollutants via ARIMA. ARIMA is widely implemented in predicting environmental health issues. The best model for predicting CVD hospital admission number was established by reviewing AIC, Q statistic, RMSE, MAPE and MAE. Only two district results used the ARIMA (0,1,1) model with single regressor O<sub>3</sub> (Kota Kinabalu) and CO(Sandakan). Keningau used the ARIMA (0,1,2) model with NO<sub>2</sub>. Only Tawau district used the ARIMA (0,1,1) model with two regressors (O<sub>3</sub> and CO). Further machine learning program utilization such as logistic regression (LR), support vector machine (SVM), artificial neural network (ANN), random forest (RF), extreme gradient boosting (XGBoost), and light gradient boosting machine (LightGBM) is recommended in future studies to develop better models to predict CVD hospitalization attributed to air pollution. In addition, climate variables such as temperature, wind speed, and radiation can be included during the analysis. Prediction model developed from this study useful for planning on appropriate measures to address the CVD hospital admission and environmental management burden. The study findings provide evidence-based information for the healthcare management team, environment policymakers, and community to sustain clean and safe ambient air in Sabah. Public transport should be efficiently available to the public to reduce city car trips. Affordable renewable energy products such as hybrid cars, solar electric, biomass boiler,

and stove are encouraged for local communities. The green building concept can be implemented in future construction or project development in these cities.

#### AUTHOR CONTRIBUTIONS

L. Salvaraji performed the literature review and the model configuration, analysed, and interpreted the data and results. R. Avoi designed the study, performed data analysis, and prepared the manuscript text. H.R.Toha help in gathering environmental data. M.S. Jeffree helped in the methodology and reviewed the manuscript text. S. Saupin provided technical input and prepared the manuscript. S.B. Shamsudin provide technical input and reviewed the manuscript.

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#### CONFLICT OF INTEREST

The author declares that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the authors. Ethical approval for this study was obtained from the Medical Research and Ethics Committee (MREC), Ministry of Health Malaysia (NMRR ID: NMRR-20-2970-57856: IIR). Secondary data consent was obtained from the Officer-in-Charge of the Health Informatic Centre, Malaysia Ministry of Health and Air Quality Unit, Malaysia Department of Environment. For hospital admission variable, only the daily number of admitted cases with CVD diagnosis were included in this study. The data excluded any information in relation to patient details.

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#### ABBREVIATIONS

%	Percent
$\mu\text{g}/\text{m}^3$	Microgram per cubic meter
AIC	Akaike Information Criteria;
AMI	Acute Myocardial Infraction
ANN	Artificial Neural Network
ARIMA	Autoregressive Integrated Moving Average
ARMA	Autoregressive moving average
CAQM	Continuous Air Quality Monitoring
CHD	Coronary Heart Disease
CO	Carbon Monoxide
COPD	Chronic Obstructive Pulmonary Disease
CVD	Cardiovascular Disease
DALYs	Daily Adjusted Life Years
DOE	Department of Environment
ELSTM	Enhanced Long Short-Term Memory
EPA	Environment Protection Agency
XGBoost	Extreme Gradient Boosting
LightGBM	Light Gradient Boosting Machine

<b>GAM</b>	Generalized Additive Model
<b>LR</b>	Logistic Regression
<b>MAE</b>	Mean Absolute Error
<b>MAPE</b>	Mean absolute percentage error
<b>MET</b>	Meteorology Department
<b>MREC</b>	Medical Research and Ethics Committee
<b>MOH</b>	Ministry of Health
<b>NMRR ID</b>	National Medical Research Registry Identification
<b>NO<sub>2</sub></b>	Nitrogen dioxide
<b>O<sub>3</sub></b>	Ozone
<b>PM<sub>2.5</sub></b>	Particulate matter 2.5
<b>PM<sub>10</sub></b>	Particulate matter 10
<b>ppm</b>	Part per million
<b>Q</b>	Q statistic
<b>RF</b>	Random Forest
<b>RMSE</b>	Root Mean Square Error
<b>SD</b>	Standard deviation
<b>SO<sub>2</sub></b>	Sulphate dioxide
<b>SPSS</b>	Statistical package for social sciences
<b>SVM</b>	Support Vector Machine
<b>USD</b>	United State Dollar
<b>WMO</b>	World Meteorology Organization
<b>WHO ICD</b>	World Health Organization International Classification of Diseases
<b>x</b>	Months
<b>y</b>	Number of CVD hospital admission

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