



IMAGE: A MAP OF THE STARS OF THE ORION CONSTELLATION

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The Effect of Plate and Magnetic Field's Inclination on Fluid Velocity of an Mhd Free Convective Poiseuille Flow

Mbai J. Mutia & Dr. Richard Opiyo

Maseno University

ABSTRACT

The current study investigated a two-dimensional free convective poiseuille flow of a viscous incompressible electrically conducting fluid flowing between two infinite inclined parallel plates at an angle α to the horizontal. An inclined magnetic field at an angle ξ with the y-axis was applied to the parallel plates. Differential governing equations were formulated and solved using numerical methods. The velocity problems from the momentum equation were graphed, revealing that the velocity increases with the rise in parallel plates' inclination angle to the horizontal, Grashof, and Hartmann numbers. Besides, increasing the magnetic field's inclination angle and the Reynolds number decreases the fluid velocity. The research findings are applicable in the manufacturing industry and crystal growth in liquids.

Keywords: free convective, inclination, MHD, poiseuille flow, runge-kutta method.

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ABSTRACT

The current study investigated a two-dimensional free convective poiseuille flow of a viscous incompressible electrically conducting fluid flowing between two infinite inclined parallel plates at an angle α to the horizontal. An inclined magnetic field at an angle ξ with the y -axis was applied to the parallel plates. Differential governing equations were formulated and solved using numerical methods. The velocity problems from the momentum equation were graphed, revealing that the velocity increases with the rise in parallel plates' inclination angle to the horizontal, Grashof, and Hartmann numbers. Besides, increasing the magnetic field's inclination angle and the Reynolds number decreases the fluid velocity. The research findings are applicable in the manufacturing industry and crystal growth in liquids.

Keywords: free convective, inclination, MHD, poiseuille flow, runge-kutta method.

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I. INTRODUCTION

Magnetohydrodynamics (MHD) is a field of science that studies the macroscopic interaction of electrically conducting fluids, including gases and liquids, with a magnetic field [5]. Here, fluid mechanics and electromagnetic equations describe the MHD flow. MHD exploitation in engineering began in the early 1960s when three technologies were innovated [4]. They included fast-breeder reactors, controlled thermonuclear fusion, and the innovation of the MHD power. The MHD power was expected to improve the power station efficiencies. Today, magnetic fields are highly utilized in metallurgical industries to heat, pump, and levitate liquid metals. Buoyancy convective flow is the motion and heat transmission process that takes place in a closed or infinite place.

The interaction between the Lorentz and buoyant forces governs the fluid flow and the temperature fields. The Lorentz force reduces the fluid velocity, suppressing the free convection currents [7].

The MHD study results in fundamental problems whose solutions are applied in several ways, including magnetohydrodynamic power generators, pumps, oil purification, and accelerators [8].

A poiseuille flow between two infinite parallel plates was researched by Manyonge *et al.* [6]. Agaie *et al.* [1] extended the work done by Manyonge *et al.* by considering a poiseuille oscillatory flow. They obtained the fluid velocity analytical expression presented in terms of Hartmann number. According to their results, a rise in the Hartmann number leads to a rise in the velocity. Poiseuille flow in the inclined channel was further investigated by Chutia [2]. They considered a two-dimensional fluid flow between two separate plates at distinct but consistent temperatures. The results reviewed showed that raising Hartmann and Reynolds numbers declines the fluid velocity while raising the Grashof number, and the inclination angle increases fluid velocity. Chutia [3] researched more on magnetic field

inclination by numerically investigating the steady MHD flow past a channel-filled permeable medium enclosed by two limitless walls. Their analysis showed that velocity decreased when the Hartmann number, magnetic inclination angle, and the permeability parameter for both poiseuille and Couette-poiseuille flows was raised.

II. NUMERICAL SOLUTION OF AN ORDINARY DIFFERENTIAL EQUATION

Studying in MHD Poiseuille flow has been of interest to many researchers, and more problems continue to evolve in the area of research. Several assumptions were set to control the nature of the problem to be solved in the current study. The two infinite parallel plates were inclined at an angle α to the horizontal. Both plates were assumed to be non-conductors, and each was maintained at a constant temperature (the lower plate: $T = T_0$, the upper plate $T = T_1$). The x-axis was positioned parallel to the parallel plates, while the y-axis was normal to the plates. An inclined magnetic field at an angle ξ with the y-axis was applied to the parallel plates. The magnetic field developed by the fluid motion was weak and hence negligible in this study, assuming that the applied magnetic field was strong enough. Both plates were considered nonconductors to avoid the secondary component of velocity.

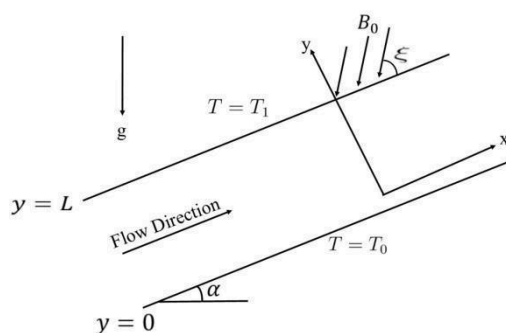


Fig. 1: Geometry of the problem

An electric field vector (E) is induced whenever a fluid velocity (V) interacts with a magnetic field (B). This vector is usually transverse to both V and B , as noted by Manyonge *et al.* [6]. Therefore;

$$E = V \times B \quad (0.0.1)$$

Let's assume that the fluid, in this case, is isotropic despite the magnetic field and use the symbol σ as a scalar that represents the fluid's electrical conductivity. The equation (0.0.2) below expresses the induced current's density in the fluid, designated J ;

$$J = \sigma(V \times B) \quad (0.0.2)$$

Lorentz Force F is a force that co-occurs with current induced;

$$F = J \times B \quad (0.0.3)$$

Therefore, using (0.0.2) and (0.0.3);

$$F = \sigma(V \times B) \times B$$

The continuity equation is the partial differential equation expressing mass conservation. It comprises only fluid density ρ and fluid velocity V .

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \rho V = 0 \quad (0.0.4)$$

The symbol ∇ represents the Gradient operator, and t stands for time. For incompressible fluid $\frac{D\rho}{Dt} = 0$ hence (0.0.4) reduces to

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \text{ two-dimensional} \quad (0.0.5)$$

Where u , v , and w are the fluid velocity in the x , y , and z -axis directions, respectively. Maxwell's Equations express the generation and variation of electric and magnetic fields. They include;

$$\nabla \cdot B = 0 \quad (0.0.6)$$

$$\nabla \times E = -\frac{\partial B}{\partial t} \quad (0.0.7)$$

$$\nabla \times H = J + \frac{\partial D}{\partial t} \quad (0.0.8)$$

Navier-Stokes Equations

The Navier-Stokes Equations for a two-dimensional steady flow are;

$$\rho \left(u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} \right) = F_x - \frac{\partial p}{\partial x} + \mu \left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right) \quad (0.0.9)$$

$$\rho \left(u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} \right) = F_y - \frac{\partial p}{\partial y} + \mu \left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} \right) \quad (0.0.10)$$

Where F_x and F_y are force components in the x and y directions, respectively, μ is the fluid viscosity, and p is the pressure acting on the fluid.

The force components in the Navier-Stokes equation F_x and F_y are mainly due to gravity. In our case, we will neglect the body forces and replace them with the Lorentz force. From equation (0.0.3), $F = J \times B = \sigma(V \times B) \times B$. Therefore, equations (0.0.9) and (0.0.10) becomes:

$$\begin{aligned} \rho \left(u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} \right) &= [\sigma[(u, 0, 0) \times B] \times B] \\ &- \frac{\partial p}{\partial x} + \mu \left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right) \end{aligned} \quad (0.0.11)$$

$$\begin{aligned} \rho \left(u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} \right) &= [\sigma[(0, v, 0) \times B] \times B] \\ &- \frac{\partial p}{\partial y} + \mu \left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} \right) \end{aligned} \quad (0.0.12)$$

respectively.

$$[\sigma[(u, 0, 0) \times B] \times B] = -\sigma u B_0^2 \sin^2 \xi i \quad (0.0.13)$$

$$[\sigma[(0, v, 0) \times B] \times B] = 0 \quad (0.0.14)$$

$$-\frac{\partial p}{\partial x} = \rho_\infty g \sin \alpha \quad (0.0.15)$$

Substituting (0.0.13), (0.0.14), and (0.0.15) in (0.0.11) and (0.0.12), respectively, and simplifying gives the following equations.

$$u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} = \frac{\rho_\infty g \sin \alpha}{\rho} - \frac{\sigma u B_0^2 \sin^2 \xi}{\rho} + \frac{\mu}{\rho} \left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right) \quad (0.0.16)$$

$$u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} = \frac{\mu}{\rho} \left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} \right) \quad (0.0.17)$$

Using the volumetric thermal expansion coefficient, be defined by;

$$\beta = -\frac{1}{\rho} \left(\frac{\Delta \rho}{\Delta T} \right)_{p=\text{constant}} = \frac{1}{\rho} \left(\frac{\rho_\infty - \rho}{T - T_\infty} \right)$$

$$\rho_\infty = \beta \rho (T - T_\infty) \quad (0.0.18)$$

Substituting (0.0.18) in (0.0.16) gives:

$$u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} = g \beta (T - T_\infty) \sin \alpha - \frac{\sigma u B_0^2 \sin^2 \xi}{\rho} + \frac{\mu}{\rho} \left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right) \quad (0.0.19)$$

Equations (0.0.17) and (0.0.19) are the resultant Momentum Equations. The associated boundary conditions for the problem include:

$$u = 0, T = T_0 \text{ at } y = 0 \quad (0.0.20)$$

$$u = 0, T = T_1 \text{ at } y = L \quad (0.0.21)$$

$$v = 0, T = T_0 \text{ at } y = 0 \quad (0.0.22)$$

$$v = 0, T = T_1 \text{ at } y = L \quad (0.0.23)$$

2.1 Similarity Transformation Technique

Similarity Transformation is a technique applied in this research to convert the non-linear partial differential equations (0.0.17) and (0.0.19) into ordinary differential equations.

A two-dimensional stream function $\psi(x, y)$ that satisfies the continuity equation is defined by $u = \frac{\partial \psi}{\partial y}$ and $v = -\frac{\partial \psi}{\partial x}$.

Let η be the similarity variable, $\theta(\eta)$ be the dimensionless temperature, and U_∞ be the fluid's velocity away from the plate. Then, the following Non-dimensionless variables are used to obtain a similarity solution to the problem:

$$\eta = y\sqrt{\frac{U_\infty}{\nu x}}, \quad \psi(x, y) = f(\eta)\sqrt{\nu U_\infty x},$$

$$\theta(\eta) = \frac{T - T_\infty}{T_1 - T_\infty} \quad (0.0.24)$$

We have the following Non-dimensionless;

$$v \frac{\partial u}{\partial y} = \frac{U_\infty^2}{2x} (\eta f'(\eta) f''(\eta)) \quad (0.0.25)$$

$$\frac{\partial^2 u}{\partial y^2} = U_\infty \sqrt{\frac{U_\infty}{\nu x}} f'''(\eta). \quad \sqrt{\frac{U_\infty}{\nu x}} = \frac{U_\infty^2}{\nu x} f'''(\eta) \quad (0.0.26)$$

$$u \frac{\partial v}{\partial x} = -\frac{U_\infty}{4x} \sqrt{\frac{\nu U_\infty}{x}} [2\eta f'(\eta) f'(\eta) + \eta^2 f'(\eta) f''(\eta)] \quad (0.0.27)$$

$$v \frac{\partial v}{\partial y} = \frac{U_\infty}{4x} \sqrt{\frac{\nu U_\infty}{x}} [\eta f'(\eta) f'(\eta) + \eta^2 f'(\eta) f''(\eta)] \quad (0.0.28)$$

$$\frac{\partial^2 v}{\partial y^2} = \frac{U_\infty}{2x} \sqrt{\frac{U_\infty}{\nu x}} [2f''(\eta) + \eta f'''(\eta)] \quad (0.0.29)$$

$$u \frac{\partial u}{\partial x} = -\frac{U_\infty^2}{2x} \eta f''(\eta) f'(\eta) \quad (0.0.30)$$

$$\frac{\partial^2 u}{\partial x^2} = \frac{U_\infty}{4x^2} [\eta^2 f'''(\eta) + 3\eta f''(\eta)] \quad (0.0.31)$$

$$\frac{\partial^2 v}{\partial x^2} = \frac{1}{8x^2} \sqrt{\frac{\nu U_\infty}{x}} [8\eta f'(\eta) + 7\eta^2 f''(\eta) + \eta^3 f'''(\eta)] \quad (0.0.32)$$

$$\text{Let } \beta = \frac{g\beta(T_1 - T_\infty)x}{U_\infty^2}, \quad Re = \frac{U_\infty x}{\nu} \text{ and } M = \frac{x\sigma B_0^2}{U_\infty \rho} \quad (0.0.33)$$

Substituting (0.0.24), (0.0.25), (0.0.26), (0.0.30), (0.0.31), (0.0.33) and $v = \frac{\mu}{\rho}$ in (0.0.19) gives;

$$4\theta Gr \sin \alpha - 4M \sin^2 \xi f' + \frac{1}{Re} [\eta^2 f''' + 3\eta f''] + 4f''' = 0 \quad (0.0.34)$$

Substituting (0.0.27), (0.0.28), (0.0.29), (0.0.32), (0.0.33) and $v = \frac{\mu}{\rho}$ in (0.0.17) gives;

$$\begin{aligned} & \sqrt{Re} [-2\eta f' f' - 8f'' - 4\eta f'''] \\ & - \sqrt{\frac{1}{Re}} [8\eta f' + 7\eta^2 f'' + \eta^3 f'''] = 0 \end{aligned} \quad (0.0.35)$$

Equating equation (0.0.34) to equation (0.0.35) and collecting the like terms together gives;

$$\begin{aligned} & 4\theta Gr \sin \alpha + \left[2\sqrt{Re} \eta f' + 8\sqrt{\frac{1}{Re}} \eta - 4M \sin^2 \xi \right] f' \\ & \left[+ \frac{3\eta}{Re} + 8\sqrt{Re} + 7\sqrt{\frac{1}{Re}} \eta^2 \right] f'' + \\ & \left[4 + 4\sqrt{Re} \eta + \sqrt{\frac{1}{Re}} \eta^3 + \frac{\eta^2}{Re} \right] f''' = 0 \end{aligned} \quad (0.0.36)$$

Equation (0.0.36) is the momentum equation to be solved with boundary conditions; with boundary conditions;

$$\begin{aligned} & f = 0, f' = 0, \theta = 1 \text{ at } \eta = 0 \\ & f' = 1, \theta = 0 \text{ at } \eta = \infty \end{aligned} \quad (0.0.37)$$

2.2 Shooting Method

The non-linear ordinary differential equations (0.0.36) with boundary conditions (0.0.37) were solved numerically using the shooting method.

III. RESULTS AND DISCUSSION

The nonlinear equations with boundary conditions were solved numerically using the shooting method. The boundary value ODEs were converted using the shooting method technique utilizing Secant iteration into a group of first-order initial values for ODEs. The fourth-order Runge-Kutta technique, incorporated within Mathematica software, was then used to solve the resulting system. In figures (fig. 2 - 6), velocity distributions were displayed for various governing parameters to analyze the results of the numerical calculations. Physically realistic numerical values were assigned to the embedded parameters in the system to obtain an insight into the flow structure for velocity.

Figure 2 shows that parallel plates' inclination angle to the horizontal impacts fluid velocity. There is a rise in fluid velocity whenever the parallel plates' angle of inclination, α , increases. The impact of the magnetic field's inclination angle (ξ) was also determined. According to Figure 3, increasing ξ decreases the fluid velocity. Figure 4 shows that there is an influence of Gr on fluid velocity. A rise in fluid velocity is expected whenever Gr value increases. Another parameter that affects fluid velocity is the Hartmann

number, M . Increasing the Hartmann number increases the fluid's velocity, as shown in Figure 5. Lastly, a Reynolds number's influence on fluid velocity was noted. A rise in its values results in a drop in the fluid velocity, as shown in Figure 6.

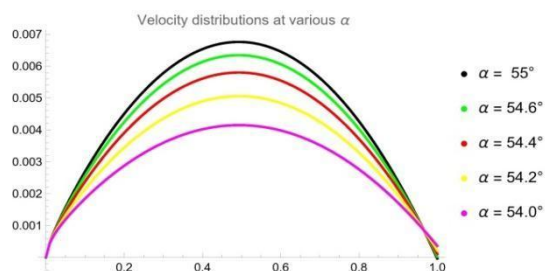


Fig. 2: Velocity at different α

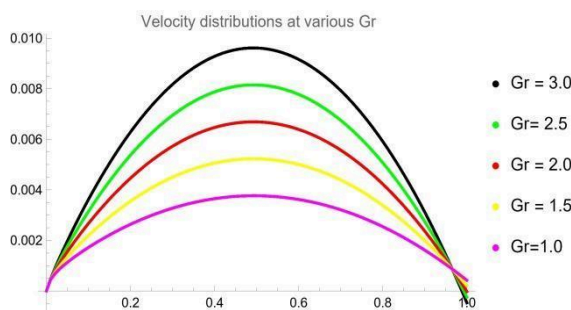


Fig. 3: Velocity at different Gr

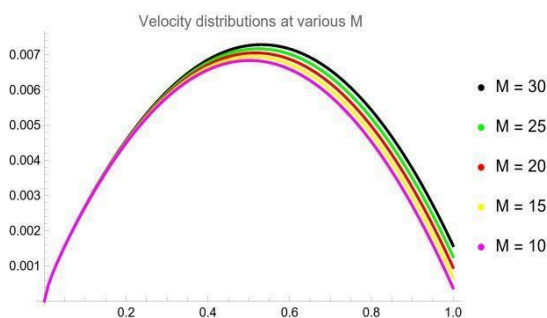


Fig. 4: Velocity at different M

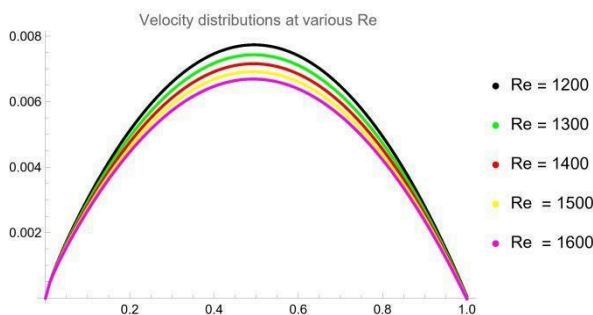


Fig. 5: Velocity at different Re

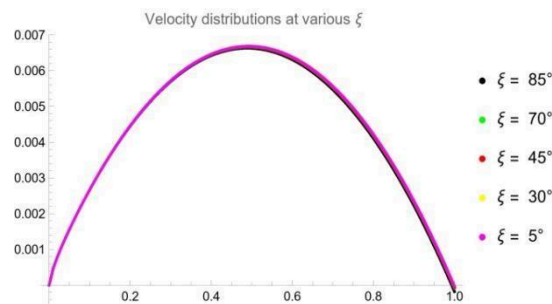


Fig. 6: Velocity at different ξ

IV. CONCLUSION

This paper examined two-dimensional steady MHD free convective Poiseuille flow past an inclined magnetic field and two infinitely inclined parallel plates. The impact of inclining the magnetic field and parallel plates and other pertinent parameters on the velocity and temperature of the fluid were discussed. Differential governing equations were formulated and solved using numerical methods. According to the results, a rise in the parallel plates' inclination angle to the horizontal, Grashof number, and Hartmann number raises the fluid velocity. Besides, increasing the magnetic field's inclination angle and the Reynolds number drops the fluid velocity. The research findings are applicable in the manufacturing industry, electrical equipment cooling, nuclear reactor insulation, and crystal growth in liquids.

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Epidemiological Profile of Asymptomatic Bacteriuria in Pregnant Women at the Mother and Child University Hospital Center of N'djamena: Associated Risk Factors and Antibiotic Resistance

Nadlaou Bessimbaye, Boyanne Gnebo Christine, Ali Senoussi Moukhtar & Abdelsalam Tidjani

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ABSTRACT

Asymptomatic bacteriuria in pregnant women is a bacterial urinary tract infection without any of the typical symptoms that are associated with a urinary tract infection whose urine culture meets the criteria for urinary tract infection corresponding to a colony count greater than 100×10^6 forming units of bacteria per liter.

The objective of this work was to determine the prevalence of asymptomatic bacteriuria in pregnant women and to evaluate the effectiveness of antibiotics against isolated bacteria to better care for pregnant women.

This is a prospective and analytical study based on the cyto bacteriological examination of urine including 185 pregnant women who came to the prenatal consultation service of the University Hospital for Mother and Child, from January 2022 to December 2022. The isolation, identification and sensitivity tests of the isolated bacteria to antibiotics were carried out under standard clinical microbiology conditions.

Keywords: asymptomatic bacteriuria, pregnant woman, antibiotic resistance, risk factor, N'Djamena.

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Epidemiological Profile of Asymptomatic Bacteriuria in Pregnant Women at the Mother and Child University Hospital Center of N'djamena: Associated Risk Factors and Antibiotic Resistance

Profil épidémiologique de bactériurie asymptomatique chez la femme enceinte au CHU-Mère et Enfant de N'Djamena : facteurs des risques associés et antibiorésistance

Nadlaou Bessimbaye^a, Boyanne Gnebo Christine^o, Ali Senoussi Moukhtar^p
& Abdelsalam Tidjani ^o

RÉSUMÉ

La bactériurie asymptomatique chez la femme enceinte est une infection bactérienne urinaire sans aucun des symptômes typiques qui sont associés à une infection urinaire dont la culture d'urine satisfait aux critères de l'infection urinaire correspondant à un taux de colonies supérieur à 100×10^6 formant des unités de bactérie par litre.

L'objectif de ce travail était de déterminer la prévalence de la bactériurie asymptomatique chez les femmes enceintes et d'évaluer l'efficacité des antibiotiques vis-à-vis des bactéries isolées pour mieux prendre en charge les femmes enceintes.

Il s'agit d'une étude prospective et analytique basée sur l'examen cyto bactériologique des urines incluant 185 femmes enceintes venues au service de consultation prénatale du Centre Hospitalier Universitaire de la Mère et de l'Enfant, allant de janvier 2022 à décembre 2022. L'isolement, l'identification et les tests de sensibilité des bactéries isolées aux antibiotiques étaient réalisés dans des conditions standards de la microbiologie clinique.

*Parmi 185 femmes enceintes qui ont bénéficié d'un dépistage à l'examen cyto bactériologique des urines, 91 (49,18%) cas étaient positifs. L'âge moyen des patientes était de 27,08 ans avec des extrêmes allant de 16 et 39 ans. La tranche d'âge de 22 à 27 ans était prédominante avec un taux de 35,16% suivie de celle de 28 à 33 ans (31,87%). Les souches bactériennes isolées étaient les *Escherichia coli* (37,63%), *Streptococcus agalactiae* (23,65%), *Klebsiella pneumoniae* (4,30%), *Mycoplasma hominis* (4,30%), *Ureaplasma spp* (3,22%) et *Pseudomonas aeruginosa* (2,15%). Les antécédents les plus fréquemment associés à la bactériurie asymptomatique étaient les infections urinaires (43,96%) suivi de 13,19% de césarienne.*

*L'antibiogramme des agents bactériens a montré une résistance moyenne de 47, 43% des *Escherichia coli* aux Bêtalactamines. 100% des *Staphylococcus aureus* étaient sensibles à l'acide fusidique et 90,91% résistants à la vancomycine. Les *Ureaplasma spp* et *Mycoplasma hominis* développent une résistance moyenne de 50% aux fluoroquinolones et 25 % aux (lincosamides, macrolides et à la tétracycline).*

Cette étude a permis non seulement de connaître le taux élevé et la fréquence des bactéries associées aux infections urinaires chez la femme enceinte, mais également montré une forte résistance des bactéries et surtout Escherichia coli aux aminopénicillines et une forte sensibilité des Staphylococcus aureus à l'acide fusidique.

Motsclés: bactériurie asymptomatique, femme enceinte, antibiorésistance, facteur de risque, N'Djamena.

ABSTRACT

Asymptomatic bacteriuria in pregnant women is a bacterial urinary tract infection without any of the typical symptoms that are associated with a urinary tract infection whose urine culture meets the criteria for urinary tract infection corresponding to a colony count greater than 100×10^6 forming units of bacteria per liter.

The objective of this work was to determine the prevalence of asymptomatic bacteriuria in pregnant women and to evaluate the effectiveness of antibiotics against isolated bacteria to better care for pregnant women.

This is a prospective and analytical study based on the cytobacteriological examination of urine including 185 pregnant women who came to the prenatal consultation service of the University Hospital for Mother and Child, from January 2022 to December 2022. The isolation, identification and sensitivity tests of the isolated bacteria to antibiotics were carried out under standard clinical microbiology conditions.

Among 185 pregnant women who were screened by urine cytobacteriological examination, 91 (49.18%) cases were positive. The average age of the patients was 27.08 years with extremes ranging from 16 to 39 years. The age group of 22 to 27 years old was predominant with a rate of 35.16% followed by that of 28 to 33 years old (31.87%). The bacterial strains isolated were Escherichia coli (37.63%), Streptococcus agalactiae (23.65%), Klebsiella pneumoniae (4.30%), Mycoplasma hominis (4.30%), Ureaplasma spp (3.22%) and Pseudomonas aeruginosa (2.15%). The antecedents most frequently associated with asymptomatic bacteriuria were urinary infections (43.96%) followed by 13.19% cesarean section.

The antibiogram of bacterial agents showed an average resistance of 47.43% of Escherichia coli to beta-lactams. 100% of Staphylococcus aureus were sensitive to fusidic acid and 90.91% resistant to vancomycin. Ureaplasma spp and Mycoplasma hominis developed an average resistance of 50% to fluoroquinolones and 25% to (lincosamides, macrolides and tetracycline).

This study not only revealed the high level and frequency of bacteria associated with urinary infections in pregnant women, but also showed a strong resistance of bacteria and especially Escherichia coli to aminopenicillins and a high sensitivity of Staphylococcus aureus to acid. fusidic.

Keywords: asymptomatic bacteriuria, pregnant woman, antibiotic resistance, risk factor, N'Djamena.

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I. INTRODUCTION

La bactériurie asymptomatique est une infection bactérienne urinaire sans aucun des symptômes typiques qui sont associés à une infection urinaire et se produit dans 2% à 15% des grossesses dont la culture d'urine satisfait aux critères de l'infection urinaire correspondant à un taux de colonies supérieur à 100×10^6 formant des unités de bactérie par litre (UFC/L) [1, 2]. En l'absence de traitement, jusqu'à 30 % des mères développeront une pyélonéphrite aiguë [3].

Les femmes enceintes qui souffrent de diabète, d'infection urinaire à répétition, de maladies polykystiques des reins, d'autres anomalies rénales congénitales et d'anémie falciforme sont exposées à un risque plus élevé de bactériurie asymptomatique et des complications associées au cours de la grossesse [4]. Les complications sous-jacentes liées à la grossesse sont la pyélonéphrite, des bas poids à la naissance, et d'accouchement prématuré [5].

En raison de risque avéré de complications pour la mère et l'enfant, le dépistage de la bactériurie chez la femme enceinte est recommandé entre la 12^{ème} et la 16^{ème} semaine coïncidant habituellement avec les premiers bilans de la grossesse [1]. Chez les femmes qui ont des antécédents d'infections urinaires à répétition, ce dépistage est recommandé tous les trimestres de la grossesse. Lorsque les résultats sont positifs, l'administration d'un antibiotique est indiquée [1, 5]. L'antibiothérapie est aussi de règle en cas de bactériurie asymptomatique avant chaque intervention génito-urinaire. La bactériurie a été longtemps considérée comme une pathologie bénigne qui ne nécessite pas un traitement, mais des études cliniques prospectives et comparatives ont montré constamment que l'antibiothérapie utilisée pour traiter la bactériurie asymptomatique diminue le risque d'infections urinaires [6]. La bactériurie asymptomatique touche 2 à 10% des femmes enceintes dans le monde [7]. En Afrique, cette prévalence varie d'une région à une autre. Elle était de 42,7%, 14%, et 8% au Nigéria, Soudan et en Algérie, en 2011, 2011 et 2013 respectivement [8, 9, 10].

Au cours de ces dernières années, on assiste à une augmentation de l'incidence des résistances aux antibiotiques des germes responsables des infections urinaires, notamment à cause de l'émergence des entérobactéries ayant une bêta-lactamase à spectre étendu [11]. Alors il convient de trouver le juste équilibre entre les risques de complication et l'augmentation de sensibilité aux antibiotiques sans consensus validé [12].

L'objectif de ce travail était de déterminer la prévalence de la bactériurie asymptomatique chez les femmes enceintes ainsi les facteurs risques associés, et d'évaluer l'efficacité des antibiotiques couramment prescrits dans notre contrée aux bactéries isolées des urines pour mieux prendre en charge les femmes enceintes au Tchad.

II. MATERIEL ET METHODES

2.1 Cadre d'étude

L'étude s'était déroulée au service de Gynéco-obstétrique du Centre Hospitalier Universitaire de la Mère et de l'Enfant (CHU-ME), au laboratoire de Bactériologie du CHU-ME de N'Djamena et à l'Unité de Bactériologie de Laboratoire de Recherches, Diagnostics et d'Expertise Scientifique (Labo-ReDES) de la Faculté des Sciences de la Santé Humaine (FSSH), Université de N'Djamena.

2.2 Type et période d'étude

Il s'agissait d'une étude prospective, descriptive, et analytique allant de janvier à décembre 2022 soit douze (12) mois

2.3 Population d'étude

La population d'étude était constituée de femmes enceintes venues à la consultation prénatale du CHU-ME.

2.4 Critères d'éligibilité

2.4.1 Critère d'inclusion

- ✓ Consentement de la femme enceinte ou de son ayant droit ;
- ✓ Possibilité de recueillir les urines dans les conditions optimales de prélèvement.

2.4.2 Critère de non inclusion

Refus de la femme enceinte à participer à l'étude.

2.5 Échantillonnage

La taille de l'échantillon était relative à la durée de l'étude, au minimum 185 échantillons étaient étudiés de type exhaustive.

2.6 Variables de l'étude

- ✓ Variables relatives aux patientes : âge de la patiente, âge de la grossesse, la parité.
- ✓ Facteurs de risque, signes cliniques, provenance, niveau d'instruction.
- ✓ Résultats des analyses microbiologiques : résultat de l'observation macroscopique et microscopique, résultat de la culture, résultat de test de sensibilité aux antibiotiques.

2.7 Prélèvement

L'urine vésicale a été recueillie de façon à éviter sa contamination par la flore commensale de la région génitale externe. Le prélèvement était réalisé au moins 4 heures après la miction précédente afin de permettre une stase suffisamment longue dans la vessie. Il a été fait selon la procédure suivante :

- ✓ Désinfection des mains avec une solution hydro-alcoolique ;
- ✓ Réalisation d'une toilette soigneuse au savon de la région vulvaire puis rinçage à l'eau et la réalisation d'un antiseptique de la zone urogénitale à l'aide d'une compresse stérile imbibée d'antiseptique ;
- ✓ Élimination des premiers jets d'urines, recueil des 20 à 30 mL suivant dans un flacon stérile en prenant soin de ne pas toucher le bord supérieur du flacon, puis le fermer hermétiquement ;
- ✓ Identification de l'échantillon et le port immédiatement au laboratoire accompagné de la fiche de collecte de données tout en indiquant l'heure du prélèvement.

L'échantillon n'était pas resté plus de 2 heures à la température ambiante, et a été conservée 24 heures à +4°C.

2.8 Analyse microbiologique

Observation macroscopique

Nous avons homogénéisé l'urine par retournement ou agitation mécanique et les aspects ont été notés.

2.8.1 Observation microscopique

Il a été réalisé à partir du culot urinaire obtenu après centrifugation à 3000/min pendant 5 min. Examen à l'état frais qui se fait entre lame et lamelle sur une cellule de Malassez afin de décrire l'aspect quantitatif et qualitatif

Quantitatif : numération des cristaux et cellules sur cellule de Malassez.

Qualitatif : Il a été réalisé à partir du culot urinaire obtenu après centrifugation de 10 mL d'urines à 2000 t/min pendant 5 min, noter la présence : cristaux, cylindres, cellules et de microorganismes (parasites) par examen direct et par examen du frottis réalisé à partir du culot de centrifugation et coloré au Gram. La présence de cellules épithéliales d'origine vaginale signe une contamination ; La culture qui permet une évaluation quantitative de la bactériurie et un antibiogramme soit manuel (identification avec galerie Api 20E et son antibiogramme en milieu gélosé de Mueller-Hinton) Frottis coloré au bleu de méthylène, la nature des cellules inflammatoires et formes des bactéries, frottis coloré au Gram.

2.8.2 Culture

Des milieux géloses solides ont été utilisés pour la culture. Le milieu CLED (cystine lactose électrolyte déficient) qui est lactose non sélectif contenant un indicateur de l'attaque du lactose était utilisé de préférence. Pour la recherche de certaines bactéries exigeantes, nous avons utilisé la gélose lactosée au sang. Le milieu Chapman a été utilisé pour la recherche des staphylocoques.

L'ensemencement par la méthode des anses calibrées nous a permis d'isoler et dénombrer les bactéries. Il s'agissait de prélever les urines à l'aide d'une anse de 10 μ L, puis les diluer dans 1 mL d'eau distillée stérile. On a ensemencé ensuite cette dilution (soit 0,001 mL d'urines sur milieu gélosé, pour une culture positive, une colonie correspond à 10^4 bactéries /mL) en faisant des étalements en plusieurs cadrans à l'aide de l'anse de sorte que toute la demi-surface de la boîte se trouvait ensemencée sans toucher les bords de la boîte. Les boîtes ont été alors mises en incubation à 37 °C dans les conditions requises. Une culture positive correspond à l'apparition, au bout de 24 à 48 heures, des colonies visibles dans le milieu de culture.

En cas d'apparition de plusieurs colonies après l'incubation, nous avons procédé à la purification qui consistait à faire des repiquages successifs des colonies déjà poussées sur le milieu CLED. La méthode consiste à prendre chaque colonie à l'aide d'une anse de platine et les répliquer chacune sur un milieu de Mueller-Hinton afin d'obtenir des colonies dites pures.

2.8.3 Lecture et interprétation de la culture

Soit N le nombre de leucocytes énumérés.

Si $N < 10^4$ /mL avec absence des bactéries, ne pas faire le GRAM.

Type de réponse : Pas de signe d'infection urinaire.

Si $N \geq 10^4$ /mL : Faire un GRAM sur le culot urinaire

Si flore polymorphe (3 types de bactéries), il s'agit des urines contaminées

Type de réponse: Refaire le prélèvement dans de meilleures conditions d'asepsie.

Si deux types de bactéries alors conclure et donner un type de réponse en se référant au diagnostic (cas de prostate, diabète, sida)

Type de réponse: Infection urinaire à tels germes...

Si un type de bactérie (flore monomorphe)

Type de réponse: Infection urinaire à...

Si $N \geq 10^4$ /mL, GRAM = 0 :

Type de réponse: Infection urinaire avec une leucocyturie significative sans bactériurie

Le malade est-il sous antibiothérapie ?

Est-ce une infection débutante ?

S'agit-il d'une suspicion de tuberculose vésicale ou rénale ? dans ce dernier cas réaliser un Ziehl-Neelsen ou coloration à l'auramine.

2.8.4 Identification Biochimique des bactéries

Une fois que la culture est positive, nous avons procédé à l'identification par la coloration de Gram pour déterminer si les bactéries sont à Gram positif ou négatif. Cela peut nous orienter sur le choix des antibiotiques que nous allons utiliser.

Nous avons utilisé la Galerie API 20E pour identifier les germes sur la base de leurs caractères biochimiques avec lequel nous avons réalisé l'antibiogramme qui nous a permis aussi d'identifier les genres et espèces de différents germes bactériens.

2.8.4.1 Galerie API 20 E

La galerie API 20 E est un système pour l'identification des Entérobactéries et autres bacilles Gram négatif, utilisant 20 tests biochimiques standardisés et miniaturisés, ainsi qu'une base de données.

❖ Principe

La galerie API 20 E comporte 20 microtubes contenant des substrats sous forme déshydratée. Les tests sont inoculés avec une suspension bactérienne. Les réactions produites pendant la période d'incubation se traduisent par des virages colorés spontanés ou révélés par l'addition de réactifs.

2.8.4.2 Mode opératoire

L'opération s'effectue selon les étapes suivantes :

- ✓ Réunir le fond et couvercle d'une boîte d'incubation et répartir environ 5 mL d'eau distillée dans les alvéoles pour créer une atmosphère humide ;
- ✓ Remplir tubes et cupules des tests avec la suspension bactérienne ;
- ✓ Remplir uniquement les tubes (et non les cupules) des autres tests
- ✓ Créer une anaérobiose dans les tests : ADH, LDC, ODC, URE, H₂S en remplissant leurs cupules avec l'huile de paraffine ;
- ✓ Refermer la boîte d'incubation, coder et placer à 37 °C pendant 18-24 heures.

❖ Lecture

Noter sur la fiche de résultat toutes les réactions spontanées. Si le glucose est positif et/ou si 3 tests ou plus *sont positifs*: révéler les tests nécessitant l'addition de réactifs.

Test VP: ajouter une goutte de réactif VP1 et VP2. Attendre au minimum 10 secondes. Une couleur rose franche ou rouge indique une réaction positive.

Test TDA (tryptophane désaminase) : ajouter une goutte de réactif TDA. Une couleur marron foncée indique une réaction positive.

Test IND (indole): ajouter une goutte de réactif de Kovacs. Un anneau rouge obtenu en 2 minutes indique une réaction positive.

La lecture de ces réactions se fait selon le profil numérique à l'aide du catalogue analytique API 20E.

2.9 Isolement et identification des *Staphylococcus aureus* et des *Streptococcus agalactiae*

Des colonies très fines observées dans le milieu CLED ont été repiquées sur le milieu sélectif Chapman et gélose chocolat par la méthode de Cadran a été faite à l'aide de l'écouvillon auprès d'une flamme de Bec Bunsen. Et les boîtes ont été incubées à une température de 37 °C pendant 24 heures.

2.10 Recherche de la catalase

Après l'isolement sur le milieu Chapman de 24 h, une colonie bien distincte a été prélevée et déposée sur une lame, une goutte de peroxyde d'hydrogène H₂O₂ sera ajoutée à la colonie.

La catalase est une enzyme qui catalyse la dégradation du peroxyde d'hydrogène (H₂O₂) en H₂O et ½ O₂. Les staphylocoques étaient positifs à la catalase. Par contre, les streptocoques étaient catalase négative.

2.11 Recherche de coagulase

La coagulase libre est présente chez *S. aureus*, mais aussi peut être produite par *S.intermedius* ou *S. hyicus*. Ce test consiste à mettre en évidence la coagulase libérée dans le milieu extérieur. La détection de cette coagulase s'effectue en ajoutant dans un tube à hémolyse 0.5 mL de plasma humain et 0.5 mL d'une culture de staphylocoques de 24 h en bouillon. Le mélange est placé à l'étuve à 37°C et est incubé pendant 24 heures. Les souches de *S. aureus* provoquant la coagulation du plasma le plus souvent les trois premières heures, un test positif se traduit par la formation d'un coagulum.

2.12 Etude de la sensibilité des bactéries isolées aux antibiotiques

2.12.1 Choix des antibiotiques

Les antibiotiques ont été choisis en fonction de leur prescription pour le traitement des infections urinaires chez la femme enceinte au service de Gynéco-obstétrique du Centre Hospitalier Universitaire de la Mère et de l'Enfant (CHU-ME).

Table 1: Antibiotiques choisis pour le test de sensibilité [13,14].

Catégorie	Famille	Antibiotique/charge	Diamètre (mm)		
			Sensibilité	Intermédiaire	Résistance
Antibiotiques (Bio-Rad)	Aminosides	Gentamicine (10 µg)	>16	14-16	<14
	B-Lactamines	Oxacilline (5 µg)	>14	8-14	<8
		Ampicilline (10 µg)	>14	12-14	<12
		Amoxicilline (25 µg)	>23	19-23	<19
		AMC (20-10 µg)	>24	18-24	<18
		Ceftriaxone (30 µg)	>31	25-31	<25
		Ceftazidime (30 µg)	>22	19-22	<19
	Cyclines	Tétracycline (30 µg)	>20	17-20	<17
	Fluoroquinolones	Lévofoxacine (5µg)	>29	23-29	<23
	Macrolides	Erythromycine (15 µg)	>29	23-29	<23
	Acide Fusidique	Acide fusidique (10 µg)	>32	26-32	<26
	Glycopeptides	Vancomycine (30 µg)	>23	17-23	<17
	7 Familles	12 antibiotiques			

Le contrôle de qualité a été effectué en utilisant les souches de référence : *E. coli* ATCC 25922 ; *Staphylococcus aureus* NCTC 12493 ; *Pseudomonas aeruginosa* ATCC 27853 ; *Klebsiella pneumoniae* ATCC 700603 ; AMC = amoxicilline acide clavulanique

2.12.2 Antibiogramme

L'antibiogramme a été fait par la méthode de KIRBY BAUER. C'est une méthode basée sur la diffusion des disques en papier imprégnés d'antibiotique sur milieu gélose (de préférence Mueller-Hinton). Les disques d'antibiotiques préalablement secs, une fois déposés à la gélose, absorbent une quantité d'eau suffisante pour dissoudre l'antibiotique qui diffuse ainsi progressivement dans le milieu suivant les lois physiques de diffusion moléculaire) travers un gel. Dans cette méthode il y a une corrélation directe entre la Concentration Minimale Inhibitrice(CMI) et la zone de diffusion. Elle est réalisée comme suit :

- ✓ *Préparation de l'inoculum*: A partir d'une culture pure et fraîche prélevée sur milieu gélosé, préparer une suspension d'une opacité équivalente au standard 0,5 MacFarland.
- ✓ *Ensemencement des boîtes*: Par écouvillonnage, ensemercer la colonie dans la gélose. Plonger un écouvillon stérile, non toxique dans de l'inoculum standardisé, l'essorer doucement sur les parois du tube contenant la suspension ; puis le passer 2 à 3 fois dans toute la surface du milieu gélose afin d'obtenir un ensemencement homogène et des colonies confluentes ;
- ✓ *Séchage des boîtes*: Laisser sécher les boîtes pendant 10 minutes avant de déposer les disques.
- ✓ *Dispositions des disques d'antibiotiques*: Déposer les disques à l'aide d'un distributeur ou à la pince en les appuyant légèrement, et les disposer à 15 mm minimum de la périphérie de la boîte de manière à ce que les zones d'inhibition ne se chevauchent pas. Il se forme ainsi un gradient de concentration de l'antibiotique autour de chaque disque ;
- ✓ *Incubation* : Incuber les géloses à 37°C pendant 24 heures ;
- ✓ *Lecture de diamètre des zones d'inhibition*: Aucune croissance n'apparaît lorsque l'antibiotique est présent aux concentrations inhibitrices et est sensible vis-à-vis de la souche. Il est alors possible de mesurer, à l'aide d'un pied à coulisse, le diamètre de la zone d'inhibition qui est directement proportionnelle aux concentrations minimales inhibitrices ;
- ✓ *Interprétation* : Après la mesure de la zone d'inhibition traduite par une zone claire autour de l'antibiotique ; on en déduit que plus le diamètre de la zone est grand plus l'antibiotique est sensible.

2.13 Détection de *Mycoplasma* et *Ureaplasma*

La galerie MYCOPLASMA IST 3 (BioMérieux, Marcy l'Etoile, France) a permis l'identification et la numération de *Mycoplasma hominis* et *Ureaplasma* spp. De plus, 6 antibiotiques pouvaient être testés. Cinq (lévofloxacine, moxifloxacine, tétracycline, érythromycine et télithromycine) étaient testés vis à vis des *Ureaplasma* et quatre (clindamycine, lévofloxacine, moxifloxacine et tétracycline) étaient testés contre *Mycoplasma hominis*.

La galerie MYCOPLASMA IST 3 est un système pour l'identification des *Mycoplasma hominis* et *Ureaplasma* spp en utilisant des tests biochimiques standardisés et miniaturisés, dans les microtubules sous forme déshydratée. Le principe est basé sur l'inoculum des microtubules avec une suspension des échantillons d'urines et ou tout autre prélèvement : le prélèvement cervico-vaginal (PCV), le prélèvement urétral (PU) et le sperme qui réhydrate les milieux. L'incubation était faite à 37° C pendant 48 heures au cours desquelles se déroulent des réactions biochimiques (décarboxylation, fermentation, désamination) qui se traduisent par des produits colorés spontanés révélés par l'addition des réactifs.

La lecture des réactions biochimiques et antibiogramme s'était faite à l'aide du contrôle positif API-MYCOPLASMA IST 3 (coloration rouge : $\geq 10^4$ - 10^6). Le contrôle positif fournissait l'identification d'un grand nombre de profils obtenus sur API-MYCOPLASMA IST 3, ce qui conférait une grande fiabilité à l'interprétation des résultats.

2.14 Interprétation des résultats de la galerie MYCOPLASMA IST 3 (Référence :422083)

Après 24 et 48 heures d'incubation (sauf *Ureaplasma* spp $\geq 10^4$ UFC : lecture à 24 exclusivement), les réactions observées des galeries et antibiogramme ont donné les interprétations (tableau 2).

Tableau 2: Interprétation des résultats de la galerie MYCOPLASMA IST 3

Paramètre	Contrôle positif	Coloration		Résultat
Identification bactérie		Positif	négatif	
<i>Ureaplasma spp</i>	rouge	rouge	jaune	positif
<i>Mycoplasma hominis</i>	rouge	rouge	jaune	positif
Antibiogramme	Contrôle positif	Coloration		Résultat
	rouge	jaune	jaune	sensible
	rouge	rouge	rouge	résistant
	rouge	jaune	rouge	intermédiaire

NB : l'interprétation des résultats de l'antibiogramme est en double coloration sauf tétracycline

2.14 Consentement éclairé écrit et signé

Madame,

Nous souhaitons effectuer le prélèvement de votre urine, il s'agit d'un geste habituellement fait pour rechercher les microorganismes responsables de l'infection urinaire.

Le prélèvement n'induit aucun risque pour votre santé, il servira à identifier le ou les pathogène (s) responsable (s) de votre problème de santé. Il s'agira en aucun cas de réaliser d'autres examens sans votre consentement. Les résultats obtenus seront mis à votre disposition et permettront sans doute de mieux savoir sur la cause de votre maladie.

Vous serez informé de tout changement de finalité de la recherche sur les échantillons et vous pourrez vous y opposer.

Madame, votre participation est primordiale pour la réalisation de cette étude qui nous permettra de contribuer à l'amélioration de votre prise en charge.

Signature et numéro de téléphone du patient

2.15 Traitement et analyse des données

À l'aide de Microsoft Office Excel et Microsoft Office Word 2019, nous avons analysé les résultats et rédigé le rapport. Le test de Khi carré a été utilisé pour étudier les relations entre les variables à la marge d'erreur limitée à 5%.

Analyse de phénotype de résistance : La proportion de résistants pour chaque antibiotique a été calculée comme la somme des antibiotiques résistants par rapport à la somme des sensibles et des résistants. La proportion de classe résistante d'antibiotique représentait la moyenne de résistance de tous les agents antimicrobiens appartenant à cette classe.

III. RÉSULTATS

3.1 Prévalence globale de la bactériurie asymptomatique

Au total, 185 femmes enceintes étaient incluses dans l'étude durant la période de 12 mois. Le résultat de la recherche de la bactériurie asymptomatique avait montré que 91 (49,19%) cultures des urines des femmes étaient positives, et 94 (50,81%) cultures étaient stériles ($p = 0,90$: différence non significative au profit de culture négative).

3.2 Répartition des patientes positive à la culture selon la tranche d'âge

La figure 1 illustre la répartition des patientes positives à l'infection bactérienne selon la tranche d'âge. La tranche d'âge la plus affectée était celle de 22 à 27 ans, suivie de 28 à 33 ans et 16 à 21 ans avec les proportions de 35,16%, 31,87% et 20,88% respectivement.

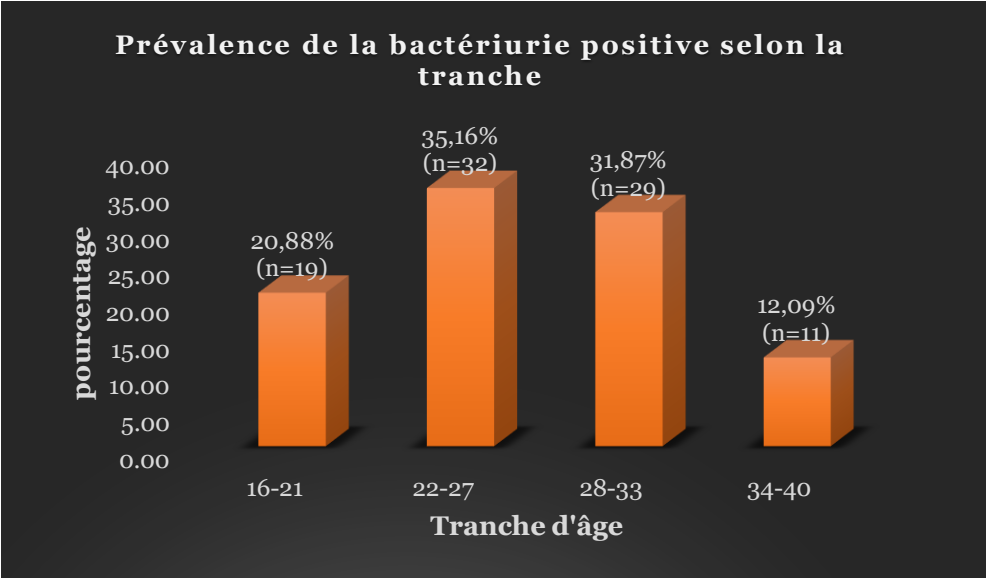


Figure 1: Répartition des patientes selon la tranche d'âge

3.3 Répartition des patientes selon l'âge de la grossesse

La figure 2 illustre la répartition de la bactériurie asymptomatique selon l'âge de la grossesse. La bactériurie asymptomatique a affecté beaucoup plus les femmes de deuxième trimestre (53%), suivie des femmes de premier trimestre (33%) et celles de troisième trimestre (14%).

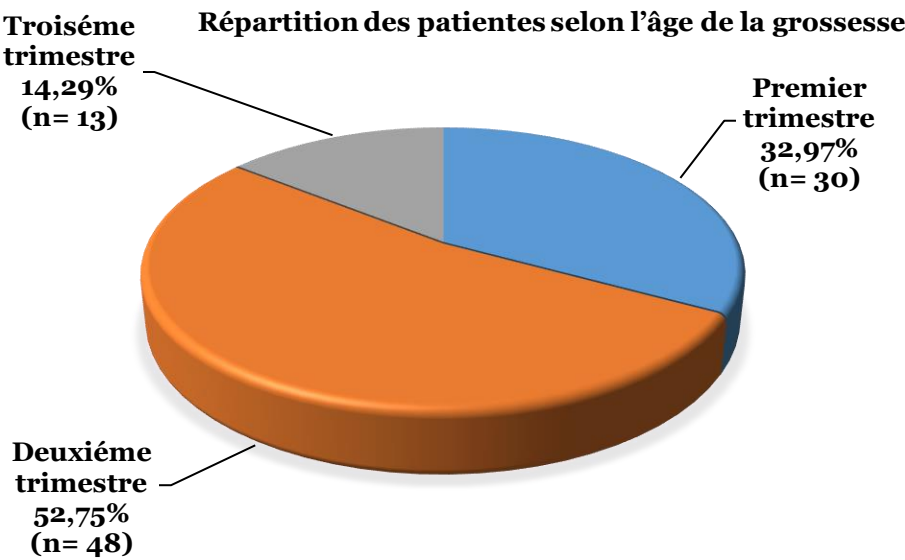


Figure 2: Répartition des patientes selon l'âge de la grossesse

3.4 Répartition des patientes selon la parité

Le tableau 3 montre la répartition des femmes infectées selon la parité. La bactériurie asymptomatique a affecté beaucoup plus les multipares (45%), suivie des primipares (32,97%) et les paucipares (20,88%) respectivement.

Tableau 3 : Répartition selon la parité

Parité	Effectif	%
Primipare	30	32,97
Paucipare	19	20,88
Multipare	41	45,05
Grande multipare	1	1,10
Total	91	100,00

Légende: Primipare : 1 enfant ; Paucipare : 2 à 3 enfants ; Multipare : 3 à 6 enfants ; Grande multipare : 6 au plus ; % = Pourcentage

Répartition des patientes selon la scolarisation

La répartition de la population infectée en fonction de leur scolarisation. La participation des femmes scolarisée à l'enquête était de 125 (67,57%) suivie de 60 (32,43%) femmes non scolarisées (p = 0,01 : il y a une différence significative en faveur de la participation des femmes scolarisées à l'enquête).

3.4 Répartition des patientes selon la profession

La figure 3 représente la répartition de la population infectée en fonction de leur profession. Les ménagères étaient les plus touchées par la bactériurie asymptomatique (52,75%) suivie des élèves/étudiantes (26,37%) et les Fonctionnaires (13,19%) respectivement.

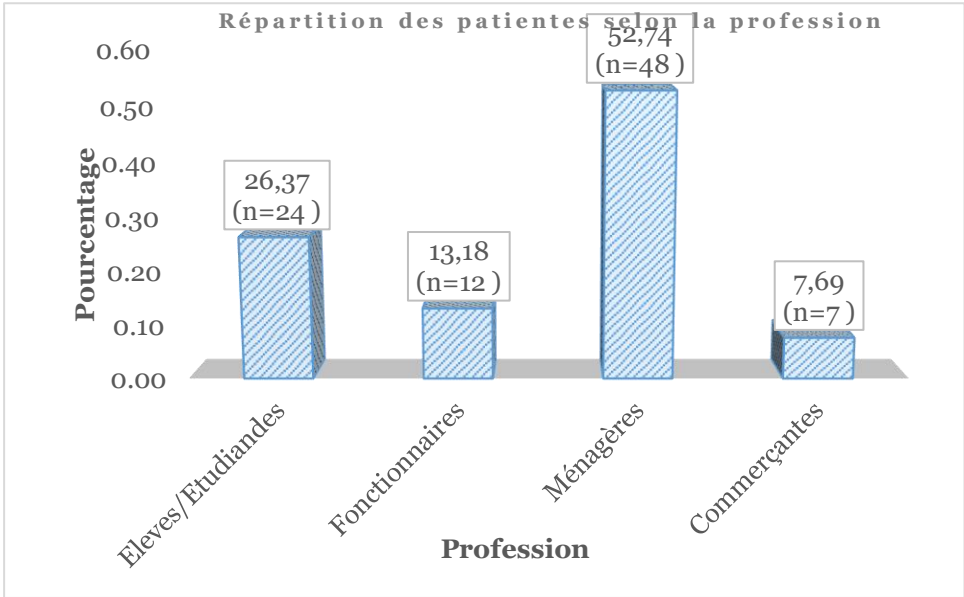


Figure 3: Répartition selon la profession

3.6 Répartition de la bactériurie asymptomatique positive selon la provenance

Les femmes urbaines étaient majoritaires avec une fréquence de 87% (80/185) contre 13% (11/1854) de provenance rurale ($p = 0,01$) : il y a une différence significative en faveur de la participation des femmes urbaines au profit des femmes rurales.

3.7 Répartition de la Bactériurie positive selon les antécédents médicaux

Le tableau 4 indique la répartition des femmes enceintes selon les antécédents médicaux. Les femmes enceintes ne présentant aucun signe médical (49,45%) étaient en tête suivies de celles ayant des infections urinaires (43,96%).

Tableau 4: Répartition de la bactériurie asymptomatique positive selon les antécédent médicaux

Antécédent médicaux	Effectif	%
VIH	3	3,30
Fausse couche	1	1,10
Déchirure du col de l'utérus	1	1,10
Kyste ovarien	1	1,10
Infection urinaire	40	43,96
Aucun signe médical	45	49,45
Total	91	100

3.8 Répartition de la bactériurie asymptomatique positive selon les antécédents chirurgicaux

Le tableau 5 montre la répartition de la bactériurie asymptomatique *positive* selon les antécédents chirurgicaux. Les femmes enceintes ne présentant aucun antécédent chirurgical étaient majoritaires (81,32%) suivies des femmes césariées (13,19%).

Tableau 5: Répartition selon les antécédents chirurgicaux

Antécédent chirurgical	n	%
Césarienne	12	13,19
Kyste	1	1,10
Hémorroïde	1	1,10
Hernie	1	1,10
Prééclampsie	1	1,10
Appendicite	1	1,10
Aucun antécédent chirurgical	74	81,32
Total	91	100

3.9 Caractéristique macroscopique et microscopique des urines

Les aspects macroscopiques des urines étaient en majorité troubles, toutefois certaines urines claires étaient révélées pathologiques notamment en cas de polyurie ou chez les immunodéprimées.

Les observations microscopiques des culots urinaires ont permis de quantifier les leucocytes, hématies, cellules épithéliales ; les cristaux (oxalate de calcium, urates, phosphate...). L'examen microscopique après coloration de Gram a permis de noter les caractères morphologiques (bacille ou cocci), Gram positif ou Gram négatif ; mode de regroupement ainsi que leurs abondances.

3.10 Répartition des cas d'infection selon le nombre de leucocytes dans les urines

Sur 91 cultures positives 33 échantillons avaient un taux $\geq 10^4$ /mL et 58 dont le taux de leucocyte était $< 10^4$ /mL. Sur 94 cultures négatives, 17 sont supérieures ou égales à 10^4 /mL et 77 inférieures à 10^4 /mL, la présence de globules blancs était considérée comme normale jusqu' à 10^4 leucocytes par millilitre d'urine.

3.11 Répartition des bactéries isolées dans les urines des femmes enceintes

Les différents germes identifiés lors d'analyse sont réparties dans le tableau 6. Les *Escherichia coli* étaient prédominantes avec un taux de 35 (37,63%) suivies de *Streptococcus agalactiae* et ensuite *Staphylococcus aureus* avec des taux de 24,73% et 23,65% respectivement.

Tableau 6: Répartition des germes isolés

Espèce bactérienne	Effectif	Pourcentage (%)
<i>Escherichia coli</i>	35	37,63
<i>Streptococcus agalactiae</i>	23	24,73
<i>Staphylococcus aureus</i>	22	23,65
<i>Klebsiella pneumoniae</i>	4	4,30
<i>Mycoplasma hominis</i>	4	4,30
<i>Ureaplasma spp</i>	3	3,22
<i>Pseudomonas aeruginosa</i>	2	2,15
Total	93	100

3.12 Résultat du test d'identification et antibiogramme des *Ureaplasma spp* et *Mycoplasma hominis* par la galerie MYCOPLASMA IST 3

La figure 4 illustre l'identification biochimique (a et c) et antibiogramme (b et d) de *Ureaplasma spp* et *Mycoplasma hominis* par la galerie MYCOPLASMA IST 3.

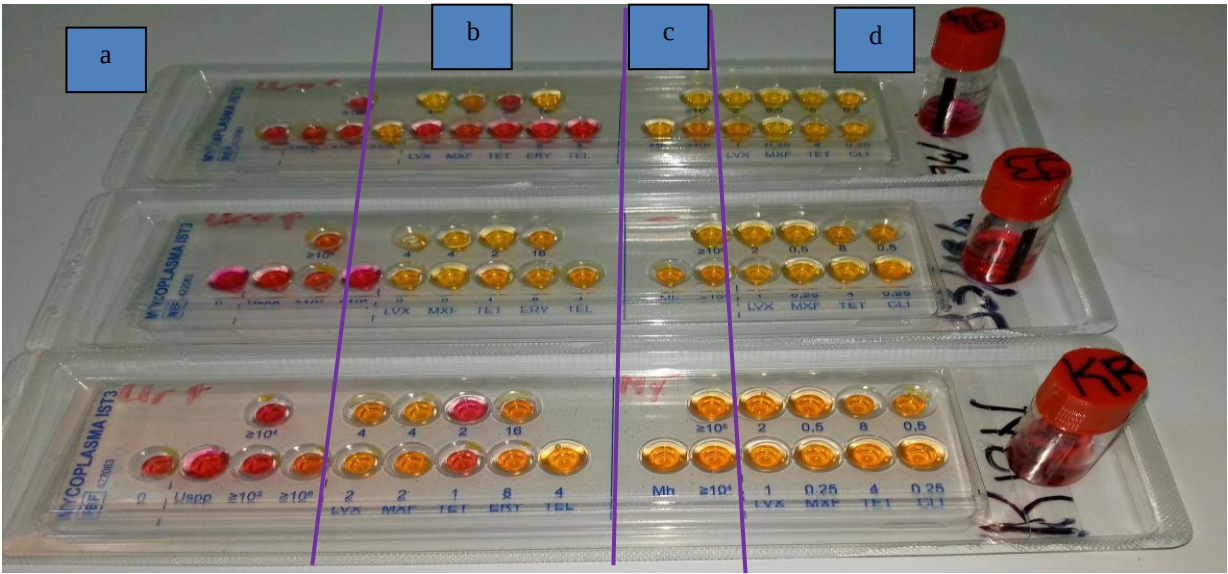


Figure 4: Identification et antibiogramme des *Ureaplasma spp* et *Mycoplasma hominis*

Légende : a : identification : *Ureaplasma spp* (rouge) ; b : LVX (lévofloxacine), MFX (moxifloxacine), TET (étracycline), ERY (rythromycine), TEL (télithromycine) ; c : absence de *Mycoplasma hominis* (jaune) ; d : (lévofloxacine), MFX (moxifloxacine), TET (étracycline), CLI (clindamycine) ; Flacon au bouchon rouge : Contrôle positif ; interprétation antibiogramme (tableau 2 ci-dessus : jaune/jaune (sensible), rouge/jaune (intermédiaire), rouge/rouge (résistant)).

3.13 Résultat de l'antibiogramme de 4 *Ureaplasma spp*

Il ressort de l'analyse de ce tableau que les *Ureaplasma spp* développent une résistance moyenne de 66,5 % vis-à-vis des fluoroquinolones, 25 % pour les macrolides et une résistance de 25 % pour la tétracycline (tableau 6).

Tableau 7: Résultat de l'antibiogramme de 4 *Ureaplasma spp*

Antibiotiques	Sensibles		Intermédiaires		Résistants	
	Effectif	Pourcentage	Effectif	Pourcentage	Effectif	Pourcentage
Lévofoxacine	1	25	0	0,00	3	75
Moxifloxacine	2	50	0	0,00	2	50
Tétracycline	2	50	1	25	1	25
Erythromycine	3	75	0	0,00	1	25
télithromycine	3	75	0	0,00	1	25

3.14 Résultat de l'antibiogramme de 3 *Mycoplasma hominis*

Il ressort de l'analyse de ce tableau que les *Mycoplasma hominis* développent une résistance moyenne de 50 % vis-à-vis des fluoroquinolones, une résistance de 33,33 % à la tétracycline et une résistance de 25 % aux lincosamides (tableau 8).

Tableau 8: Résultat de l'antibiogramme des 3 *Mycoplasma hominis*

Antibiotiques	Sensibles		Intermédiaires		Résistants	
	Effectif	Pourcentage	Effectif	Pourcentage	Effectif	Pourcentage
Lévofoxacine	1	25	0	0,00	2	75
Moxifloxacine	2	75	0	0,00	1	25
Tétracycline	1	33,33	1	33,33	1	33,33
clindamycine	2	75	0	0,00	1	25

3.15 Evaluation de l'efficacité de 86 agents bactériens isolés aux antibiotiques

La fréquence sans cesse accrue des infections bactériennes associées à la bactériurie chez la femme enceinte et l'émergence rapide des souches résistantes à la plupart des antibiotiques, impose, désormais, les tests de la sensibilité aux antibiotiques utilisés en thérapeutique, pour chaque souche isolée de bactéries. D'une manière générale (tableau 8), les 86 bactéries isolées ont développé des sensibilités diminuées aux aminopénicillines. Les souches de *Staphylococcus aureus* étaient toutes sensibles à l'acide Fusidique et fortement résistantes (90,91%) à la vancomycine. Les *Escherichia coli* développent une résistance moyenne (28%) avec (ceftriaxone, ceftazidime et amoxicilline + acide clavulanique). Les *Klebsiella* développent une résistance de 100% vis-à-vis de la gentamicine. Les *Streptococcus agalactiae* développent une sensibilité remarquable et une résistance à la vancomycine avec les proportions de 14 (60,87%) et 8 (34,78%) respectivement. Les *Pseudomonas aeruginosa* étaient sensibles à 100% à la ceftazidime et résistantes à 100% à l'amoxicilline + acide clavulanique. Les 86 bactéries ont développé une sensibilité moyenne de 75% et de résistance moyenne de 25% à la tétracycline et à lévofoxacine (tableau 9).

Tableau 9: Evaluation de l'efficacité des antibiotiques aux 86 bactéries isolées

ATB	Espèce bactérienne									
	<i>Escherichia coli</i> (n = 35)		<i>Staphylococcus aureus</i> (n = 22)		<i>Streptococcus agalactiae</i> (n = 23)		<i>Klebsiella pneumoniae</i> (n = 4)		<i>Pseudomonas aeruginosa</i> (n = 2)	
	S (%)	R+I (%)	S (%)	R+I (%)	S (%)	R+I (%)	S (%)	R+I (%)	S (%)	R+I (%)
GNN	28 (80)	7 (20)	11 (50)	11 (50)	17 (74)	6 (26)	0 (0)	3 (100)	1 (50)	1 (50)
AMP	7 (20)	28 (80)	17 (48,57)	18 (51,42)	8 (34,78)	15 (65,22)	0 (0)	4 (100)	0 (0)	2 (100)
OXA	NR	NR	13 (56,52)	9 (40,91)	15 (65,21)	8 (34,78)	NR	NR	NR	NR
AMX	9 (25,71)	26 (74,28)	8 (36,36)	12 (54,54)	14 (60,87)	9 (39,13)	0 (0)	4 (100)	0 (0)	2 (100)
AMC	21 (60)	14 (40)	13 (59,09)	9 (40,90)	16 (69,56)	7 (30,43)	1 (25)	3 (75)	0 (0)	2 (100)
CRO	27 (71,14)	9 (25,71)	16 (72,72)	6 (27,27)	18 (78,26)	5 (21,73)	3 (75)	1 (25)	1 (50)	1 (50)
CAZ	29 (82,85)	6 (17,14)	17 (72,27)	5 (22,72)	15 (62,21)	8 (34,78)	2 (50)	2 (50)	2 (100)	0 (0)
ERY	NR	NR	18 (81,81)	4 (18,18)	19 (82,61)	4 (17,39)	NR	NR	NR	NR
TET	21 (60)	14 (40)	13 (59,09)	9 (40,90)	15 (65,21)	8 (34,78)	3 (75)	1 (25)	1 (50)	1 (50)
LVX	25 (71,42)	10 (28,57)	17 (77,27)	5 (22,72)	19 (82,61)	4 (17,39)	3 (75)	0 (25)	2 (100)	0 (0)
AF	NR	NR	22 (100)	0 (0)	NR	NR	NR	NR	NR	NR
VCN	NR	NR	2 (9,09)	20 (90,91)	14 (60,87)	8 (34,78)	NR	NR	NR	NR

Légende : ATB= antibiotique ; n= nombre ; % (R+I) = pourcentage de résistance ; S = pourcentage de sensibilité ; NR= non requis ; % = pourcentage
Gentamicine (GNN) ; Ampicilline (AMP) ; Amoxicilline (AMX) ; Amoxicilline +acide clavulanique (AMC) ; Ceftriaxone (CRO) ; Ceftazidime (CAZ) ; Lévoﬂoxacine (LVX) Tétracycline (TET) ; Acide fusidique (AF)

IV. DISCUSSION

Durant les 12 mois d'étude, 185 femmes enceintes étaient incluses et prélevées pour la recherche de la bactériurie asymptomatique. L'analyse bactériologique des urines a décelé 91 cas positifs soit une prévalence de 49,19%. Cette prévalence était supérieure à celles de Jalali et al qui avait obtenu 19,8% en Iran en 2014 [15] et kalla et al 3,9% en Algérie en 2018 [16]. Elle était similaire à celles obtenues par Boulakehal qui était de 48,5% en Algérie en 2016 [17] et Wingert et al qui avaient rapporté 42,7% au Canada en 2017 [8]. Mais largement inférieure à celle de Glaser et Schaeffer qui avaient obtenu 68% [18]. La prévalence élevée de la bactériurie asymptomatique dans cette série pourrait être attribuée à plusieurs facteurs tels que, le statut socio-économique faible comme l'âge de mariage, l'âge du premier rapport sexuel, aux conditions de vie défavorable à la survenue de l'infection urinaire et au manque de règles élémentaires d'hygiène. Ce pendant les facteurs tels que, le sexe du fœtus et diabète n'ont eu aucun effet significatif sur la prévalence de la bactériurie asymptomatique.

Les infections urinaires peuvent affecter la femme enceinte quel que soit son âge. L'âge moyen était de 27,08 ans avec des extrêmes de 16 et 39 ans. La tranche d'âge de 22 à 27 ans était la plus représentée avec un taux de 35,16%. La prédominance à cette tranche d'âge n'est pas significative, mais pourrait être expliquée par le désir de maternité accru à cette tranche d'âge, et aussi la période qui correspond généralement à la première grossesse. Awonuga et al n'avaient pas trouvé d'association statistiquement significative entre l'âge et la bactériurie asymptomatique au Nigeria en 2011 [9]. Par contre, Taale et al avaient obtenu une prédominance entre 21 et 30 ans avec un taux de 59,7% au Bénin en 2016 [19]. La survenue de la bactériurie asymptomatique ne dépend pas de l'âge, elle est liée à l'activité sexuelle qui varie selon l'âge, ce qui pourrait expliquer que les femmes enceintes de 15 à 20 ans sont les plus vulnérables aux infections urinaires. Ces jeunes femmes étaient aux premières étapes de leur vie sexuelle active, le rôle de rapport sexuel paraît justifier une telle situation. Selon plusieurs auteurs, les rapports sexuels sont un élément essentiel de la genèse de l'infection urinaire chez la femme [3, 20, 23].

Parmi les 91 échantillons positifs, 33 échantillons d'urine avaient révélé une leucocyturie significative avec un taux $\geq 10^4$ mL et un taux de $58 \leq 10^4$ mL. 17 échantillons avaient révélé un taux $\geq 10^4$ mL mais avec une culture négative, il pourrait s'agir d'échantillons d'urines provenant des patientes sous antibiothérapie ou sous un anti-inflammatoire. Pour ceux présentant une leucocyturie non significative

cela pourrait être expliqué par un début d'infection, cependant une leucocyturie significative ne signifie pas toujours la présence d'une infection urinaire.

En termes de l'âge de la grossesse, dans cette étude la fréquence de la bactériurie asymptomatique était plus élevée, au deuxième trimestre avec un taux de 52,75% suivie des femmes du premier trimestre 32,97% et celle de troisième trimestre 14,29%. Ces résultats étaient similaires à ceux obtenus par Gauzit et al en 2021 qui avaient mentionné une prédominance des infections au deuxième trimestre suivi du premier trimestre [21]. Ceci a été aussi observé par Olsen et al à Tanzanie en 2010 [22]. Dans l'étude de Awonuga et al, la prévalence de la bactériurie asymptomatique augmente avec l'âge gestationnel avec des taux de 6,5%, 11,2%, 12,2% correspondant respectivement au premier, deuxième et troisième trimestre de grossesse [9]. Ce qui pourrait s'expliquer par la négligence de la consultation prénatale, cette négligence serait liée à la méconnaissance par les femmes enceintes au premier trimestre de la grossesse. La prédominance de l'infection urinaire chez la femme enceinte augmente du premier trimestre au troisième trimestre ce qui pourrait être expliqué par la stase urinaire, due à la compression exercée par l'urètre gravide sur la vessie et les uretères. Par ailleurs, plusieurs auteurs ont relevé que le deuxième trimestre était la période de prédilection de l'infection urinaire (IU) [23, 24]. Par contre Bahloul et al avaient trouvé une fréquence plus élevée de l'infection au troisième trimestre de grossesse [25].

Les multipares étaient les plus représentés soit une fréquence de 45% suivie des primipares avec 32,97%. Ce résultat corrobore celui de Boulakehal et al en 2016 en Algérie qui avaient obtenu 34% des femmes multipares ayant une bactériurie asymptomatique [17]. Par contre Wullt et al en avaient obtenu une prédominance de 40% des primipares [26]. Ceci pourrait être expliqué que la bactériurie était significativement associée à la parité et aux antécédents d'infection urinaire.

Les femmes ménagères étaient la couche socioprofessionnelle la plus touchée avec une fréquence de 52,75%. Ceci était dû au fait que la majorité des femmes reçues à la consultation prénatale (CPN) pendant cette étude étaient des femmes au foyer, suivie des élèves et étudiantes (26,27%). Par contre elle est plus basse chez les fonctionnaires et les commerçantes avec des taux de 13,19% et 7,69% respectivement. Cela pourrait s'expliquer par le mariage précoce, le poids de la tradition qui considère la femme comme n'ayant droit à d'autre activité que celle d'entretenir la maison et faire des enfants.

L'antécédent de l'infection urinaire est considéré comme le principal facteur de risque de la bactériurie asymptomatique. Dans cette étude 43,96% des femmes ayant une bactériurie asymptomatique avaient des antécédents d'infection urinaire. Ce résultat se rapproche à celui de Alemu et al en Éthiopie en 2012 [13] qui avaient obtenu 32,5% des femmes avec une association statistiquement significative entre l'antécédent de l'infection urinaire et la bactériurie asymptomatique.

En ce qui concerne l'identification des bactéries dans les urines des femmes enceintes, plusieurs espèces bactériennes ont été impliquées dans les infections urinaires à savoir les cocci gram positif. Les résultats de l'examen cytot bactériologique des urines (ECBU) avaient montré une prédominance des *Staphylocoques* : les *Escherichia coli* 35 (37,63%), *Staphylococcus aureus* avec un taux de 22 (23,65%) suivis des *Streptococcus agalactiae* 23 (24,73%), *Klebsiella pneumoniae* (4,30%). Ces résultats sont superposables à celui de Zariane et al au Bénin en 2015 [24] qui avaient obtenu majoritairement des 25% de *Staphylococcus aureus*, 11,54% de *Staphylococcus epidermidis* suivis de 10,58% *Escherichia coli* soit et de 8,65% *Klebsiella pneumoniae*. Ces résultats étaient inférieurs à celui de Bahloul en 2017 qui avaient obtenu : 7,32% *Staphylococcus aureus*, 4,88% *Staphylococcus saprophytes* et 4,88% *Klebsiella pneumoniae* [25]. Par ailleurs, Lilaz et al en 2015 avaient documenté que les staphylocoques sont souvent mis en cause dans les infections urinaires [26]. Cela pourrait être expliqué par la présence de l'acide lipotéichoïque contenu dans leur paroi cellulaire et qui sont utilisés comme facteur d'adhésion pour survivre dans le tractus urinaire.

Dans cette série, 4,30% des *Mycoplasma hominis* et 3,22% de *Ureaplasma* spp étaient identifiés. Jingjuan et al en Chine dans une étude non ciblée ont obtenu des taux élevés de *Mycoplasma hominis* et *Ureaplasma* spp avec des prévalences de 38,1% et 31,3% respectivement. Cette variation des prévalences pourrait s'expliquer par la différence de taille de l'échantillon et d'autre part c'est parce que cette série d'études était ciblée sur les femmes enceintes par rapport à celui de Song et al en 2022 en Chine [27].

Parlant de la sensibilité aux antibiotiques, les *Mycoplasma hominis* développaient une résistance moyenne de 50 % vis-à-vis des fluoroquinolones, une résistance de 33,33 % à la tétracycline, et une résistance de 25 % aux lincosamides. Les *Ureaplasma* spp développaient une résistance moyenne de 66,5 % vis-à-vis des fluoroquinolones, 25 % pour les macrolides et une résistance de 25 % pour la tétracycline. Au Mali en 2022, Guindo et al avaient obtenu des prévalences de résistance qui variaient entre 87 et 9,2 % pour les fluoroquinolones, 23 et 57 % pour les macrolides et la tétracycline. La pristinamycine et la doxycycline ont conservé leur activité contre les mycoplasmes avec une faible résistance variant entre 10,7% pour la pristinamycine et 7,7% pour la doxycycline [28]. La présente étude a révélé une résistance de 47,43% aux Bêta-lactamines (ampicilline, amoxicilline, amoxicilline acide clavulanique et céftriaxone) vis-à-vis d'*Escherichia coli*. Ces résultats pourraient être expliqués par la production de pénicillinase et céphalosporines des germes en question. Ces résultats sont similaires à ceux de Guelmbaye et al en 2015 au Tchad, qui avaient identifié 54,5% des souches d'*Escherichia coli* productrices de bêta-lactamase à spectre élargi impliquées dans les infections urinaires [29], Fissou et al en 2019 avaient isolé 24,73% d'*Escherichia coli* et 10,75% de *Klebsiella pneumoniae* responsables des infections urinaires avec des taux supérieurs de résistance à l'amoxicilline (96,66%-100%) et plus bas au cefotaxime (16,33%), gentamycine (28,33%-39,9%), acide nalidixique (65-95%), et fosfomycine (8,3-13,04%) respectivement [30]. Les 22 souches de *Staphylococcus aureus* isolées dans cette étude étaient toutes sensibles à l'acide Fusidique, fortement résistantes (90,91%) à la vancomycine et 71,42% sensibles à lévofloxacine Les résultats de tests de sensibilité de cette étude sont également superposables aux travaux antérieurs [31, 32, 33, 34].

Concernant les facteurs de risque associés à la bactériurie asymptomatique, un traitement antibiotique pourrait réduire le risque d'infection des reins chez les femmes enceintes qui avaient une infection urinaire mais ne présentant aucun symptôme d'infection, pourrait également être efficace pour réduire les risques qu'un bébé naisse trop tôt ou ait un faible poids à la naissance [35].

V. CONCLUSION

La présente étude a permis de déterminer une forte prévalence des bactéries responsables de la bactériurie asymptomatique chez la femme enceinte ainsi que la caractérisation de profil de résistance aux antibiotiques couramment utilisés pour la prise en charge des femmes enceintes au Tchad. Il ressort de cette étude que la bactériurie asymptomatique est plus fréquente et survient dans la plupart des cas pendant le deuxième et premier trimestre de grossesse et une prédominance à la multipare et primipare. Cette étude a également indiqué que les staphylocoques étaient les germes les plus fréquents et plus incriminés à la bactériurie asymptomatique suivis d'*Escherichia coli* et *Klebsiella pneumoniae*. L'antécédent de l'infection urinaire était souvent l'un des facteurs de risques de la bactériurie asymptomatique.

Au vu de ces résultats, nous recommandons la réalisation des études élargies au niveau national afin de mieux connaître les germes les plus impliqués à la bactériurie asymptomatique et conseillons la prescription de l'acide fusidique aux femmes en état de maternité dans notre contrée.

Déclaration de conflit d'intérêts

Les auteurs ne déclarent aucun conflit d'intérêt.

Contribution des auteurs

Tous les auteurs ont contribué de manière significative à la rédaction et à l'édition de ce manuscrit. Il a été vu et approuvé par tous les auteurs. Ce manuscrit n'a pas été envoyé pour publication ailleurs.

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ABSTRACT

In June 2021, emeritus professor at the University of British Columbia and a member of the Club of Rome, William E. Rees —the author of the ecological footprint concept— presented the conference “The Enigma of Climate Inaction,” which has been widely discussed. In this essay we join that discussion and, consequently, we present our point of view about the reasons that have led humanity to the situation in which it is trapped and from which, unfortunately, it seems it will not be able to escape. We end the text, however, proposing some alternative solutions to the socio-environmental crisis coming from the teachings of some indigenous peoples.

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Reasons for Environmental Crime

Luis Tamayo Pérez^a & Antonio Sarmiento Galán^o

RESUMEN

En junio del 2021, el profesor emérito de la University of British Columbia y también integrante del Club de Roma, William E. Rees —el autor del concepto de huella ecológica— presentó la conferencia “The Enigma of Climate Inaction”, la cual ha sido ampliamente discutida. En este ensayo nos sumamos a esa discusión y, en consecuencia, presentamos nuestro punto de vista acerca de las razones que han conducido a la humanidad a la situación en la que se encuentra atrapada y de la que, desgraciadamente, parece no podrá salir. Al final, sin embargo, plantearemos algunas alternativas de solución a la crisis socioambiental provenientes de las enseñanzas de algunos pueblos originarios.

Palabras clave: cambio climático, crisis social, colapso.

ABSTRACT

In June 2021, emeritus professor at the University of British Columbia and a member of the Club of Rome, William E. Rees —the author of the ecological footprint concept— presented the conference “The Enigma of Climate Inaction,” which has been widely discussed. In this essay we join that discussion and, consequently, we present our point of view about the reasons that have led humanity to the situation in which it is trapped and from which, unfortunately, it seems it will not be able to escape. We end the text, however, proposing some alternative solutions to the socio-environmental crisis coming from the teachings of some indigenous peoples.

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I. INTRODUCTION

Almost a century ago, the psychoanalyst Jacques Lacan titled “Motifs du crime paranoïaque” his proposed reading of a crime that occurred in the city of Mans —Mrs Lancelin and her daughter were viciously murdered by their maids— and that, for the Psychiatry and the law of his time were difficult to understand. Similarly, in this essay we will approach the understanding of a phenomenon that William E. Rees calls “enigmatic”: the inaction of humanity in the face of that which threatens to end the conditions that make its very existence possible: Anthropogenic Global Warming.

II. ON THE CIVILIZATIONAL COLLAPSE

That humanity is approaching a large-scale global collapse is something admitted not only by the main institutions dedicated to the study of the Earth's climate —Intergovernmental Panel on Climate Change, National Oceanic and Atmospheric Administration, World Meteorological Organization, Copernicus Marine Service, Potsdam-Institut für Klimafolgenforschung, among others— but by the Secretary General of the United Nations himself, António Guterres, who is taking advantage of every forum at his disposal to try to alert humanity because, as he indicated on July 27, 2023, we are no longer in the era of global warming but in that of global boiling.

The approaching collapse is not the one that Richard Duncan described at the beginning of the century —since oil shortages will not be its main component— but rather a socio-environmental crisis of

extraordinary dimensions. The predictions of the Club of Rome raised in *The limits to Growth* (1972) have proven accurate and in its most recent study, written by Sandrine Dixson-Declève et al., *Earth for All* (2022) indicates that, if the measures necessary to stop Global Warming, a socio-environmental crisis of such dimensions will occur as soon as 2050 that could reduce humanity by almost a half by the end of this century.

2.1 The stages of such collapse were described very convincingly by Peter Goodchild

The collapse of modern industrial society has 14 parts, each with a somewhat causal relationship to the next. (1) Fossil fuels, (2) metals, and (3) electricity, are a tightly-knit group, and no industrial civilization can have one without the others. The decline in fossil-fuel production is the most critical aspect of the collapse, and most of the following text will be devoted to that topic. As those three disappear, (4) food and (5) fresh water become scarce; grain and wild fish supplies per capita have been declining for years, water tables are falling everywhere, rivers are not reaching the sea. Matters of infrastructure then follow: (6) transportation and (7) communication, no paved roads, no telephones, no computers. After that, the social structure begins to fail: (8) government, (9) education, and (10) the large-scale division of labor that makes complex technology possible. After these 10 parts, however, there are four others that form a separate layer, in some respects more psychological or sociological. We might call these “the four Cs.” The first three are (11) crime, (12) cults, and (13) craziness; the breakdown of traditional law; the ascendance of dogmas based on superstition, ignorance, cruelty, and intolerance; the overall tendency toward anti-intellectualism; and the inability to distinguish mental health from mental illness. There is also a final and more general part that is (14) chaos, resulting in the pervasive sense that “nothing works anymore.”¹

Such stages are already beginning to occur in those places on the globe where natural-artificial catastrophes—that is, those that, like Hurricane Otis in Acapulco, which went from being a simple and natural tropical storm to a devastating category 5 hurricane due to the global warming generated by our greenhouse gas emissions— have taken hold and devastate entire towns and nations.

2.2 The effects of Anthropogenic Global Warming are also seen in other places:

We know well that, as predicted by the NOAA Climate Prediction Center, in the years 2023 and 2024, the meteorological phenomenon known as El Niño (ENSO) is causing a disproportionate increase in the frequency and intensity of all hydrometeorological phenomena (floods, heat waves, droughts and hurricanes). The forest fires that Canada suffered between April and June 2023 were the most extensive in its history, burning 10 million hectares and displacing 120,000 people. And the same thing happened in Greece, Türkiye and Portugal. Such fires did not fail to affect the permafrost of the northernmost regions of the earth, which, when melting, increased methane emissions and these, in turn, increased the overheating of the earth.

Such phenomena are slowing down the thermohaline current that circles the planet. In this regard, on February 9, 2024, the study “Physics-based early warning signal shows that AMOC is on tipping course” was published in the journal *Science Advances* by three researchers from Utrecht University: R. M. van Westen, M. Klipuis and H. Dijkstra. Their study shows that the Atlantic Meridional Overturning Circulation (AMOC) could collapse if humanity continues to emit such enormous amounts of greenhouse gases (GHGs) as it does now. Since the AMOC is part of the thermohaline current that runs through all the seas of the world carrying heat, humidity and nutrients from the equator to the poles and the European subcontinent obtains its temperate climate thanks to the heat and humidity coming from the AMOC, if it did not exist, the European climate would be like that of similar latitudes on the

¹ Goodchild, 2010.

American continent. For example, the large cities of Norway, Sweden, Finland, the United Kingdom or Russia, since they are located on the same latitude as the vast uninhabited regions of Canada, would suffer the same intense cold that prevents such Canadian regions from being massively inhabited. The study also indicates that the phenomenon of the slowdown of the AMOC has already begun and, consequently, it has lost two thirds of the strength it had a century ago. And if greenhouse gas (GHG) emissions are not significantly reduced, it could lose 90% of its strength in a period between 25 and 50 years, causing much of Europe to freeze.

The year 2023 has been described as “the warmest in all recorded history.” And 2024 is expected to be even worse as its first three months have already set record temperatures.

In the years 2023-2024 the earth is giving us a sample of what the “normal” climate will be in the coming decades if we do not stop the GHG emissions responsible for Anthropogenic Global Warming. In these months, humanity will enjoy one last opportunity that, perhaps, could make us wake up to the reality of global warming.

It is for no other reason that, as we indicated before, the current Secretary General of the United Nations Organization takes advantage of all the forums at his disposal to indicate that we are in a climate emergency that threatens to cause enormous suffering not only to humanity but to many other species. And Guterres is not the only one trying to alert humanity. Years before, the Intergovernmental Panel on Climate Change indicated in its 6th Report (IPCC, 2021) that if in 2030, humanity does not manage to reduce greenhouse gas emissions by half, it will be practically impossible to cancel them in 2050 which is a key element to maintain the Paris Agreement signed by 196 nations in 2015 and endorsed in Dubai in 2023.²

However, despite the evidence and warnings, and as Dr. Rees emphasizes, humanity simply does not react... Why?

III. OF THE REASONS FOR INACTION

In his study *Où atterrir*, Bruno Latour offers us his point of view regarding the causes of the ongoing civilizational collapse:

[...] the elites have been so convinced that there would be no future life for everyone that they decided to get rid, as quickly as possible, of all the burdens of solidarity: that is deregulation. That a kind of golden fortress had to be built for the small percentage that would manage to be safe: that is the explosion of inequalities. And that, to disguise the gross selfishness of this flight from the common world, its original motivation had to be rejected outright: that is the denial of climate change (Latour, 2019: 28).

Although we fundamentally agree with Latour, we cannot help but notice that his assessment implies the existence of a super-powerful, well-organized and educated group—the “elites”—which would be behind all the evils caused to humanity.

From our point of view it is not necessary to assume the existence of such a powerful entity. It is enough to carefully examine the way in which the global economy has developed to appreciate that the devastation of the planet that is taking place today is simply necessary or, to put it in the words of Hannah Arendt, banal.³

²<https://www.france24.com/es/medio-ambiente/20231208-nuevo-borrador-de-la-cop28-el-fin-del-uso-de-los-combustibles-fosiles-sobre-la-mesa>

³ In this regard, let us remember that Hannah Arendt (1963), in her book *Eichmann in Jerusalem*, presented the concept of the banality of evil to explain the behaviors that led to one of the worst genocides carried out by humanity.

IV. A MULTI-CAUSED COLLAPSE

From our point of view, there are multiple factors that, in our days, add up to motivate human inaction in the face of the approaching civilizational collapse:

4.1 Ignorance

Ignorance regarding what is happening with the world's climate is a primary reason for inaction. Someone might say: "I haven't noticed that the climate is changing and, therefore, I haven't asked myself anything and I'm not doing anything about it." However, given that Anthropogenic Global Warming (AGW) has been generating innumerable effects throughout the earth, we consider that more than pure and simple ignorance, in this case it is a phenomenon such as that described by Robert Proctor in his *Agnotology* (2008): ignorance regarding the AGW has been induced by dark interests. Let us remember that Proctor in his book *Agnotology: Why don't we know what we don't know?*⁴ maintains that agnotology revealed its importance after the tobacco crisis of the middle of the last century, that is, when cases of lung cancer associated with tobacco consumption increased and made the causal link increasingly evident while, at the same time, "serious" —and highly publicized— studies appeared that dissociated it, such as the advertising campaigns: "Doctors smoke Camel" or that of Chesterfield cigarettes, which claimed to have "scientific evidence" of the health benefits of its product.⁵ In the case of the cancer-smoking association, humanity learned that big tobacco companies and the scientists associated with them were capable of lying out of interest.

From our point of view, what is now happening with those who claim that there is no clear evidence of climate change, that on earth "cyclical climatic variations have always existed", they are simply under the effects of agnotology: their ignorance —and their inaction as a result— has been created by the worst interests. Likewise, it is from this source that climate change deniers emanate.

4.2 Militarization

Nowadays, practically all the nations on earth are militarized, and above all, the most powerful. The military, consequently, are very close to the decision makers —or they themselves are— and their ideology —"defender of the nation's high values"— continues to prevail in discussions. The soldiers of all nations have, consequently, a precise objective that has been imprinted on them since their years in the academy: to defend their homeland from enemies. The enemy is anyone who, in one way or another, affects, or could affect, the interests of the nation. That is why, if a sovereign nation with whom I share a border decides to join a group of nations that I consider enemies, it could be grounds not only for sanctions but for an invasion! Just as Putin's Russia did with Ukraine.

For a soldier, trained as we previously indicated in the defense of his nation, there is nothing more incomprehensible than "planetary consciousness", than the "union of humanity", than human cooperation and solidarity.

The *urgent* items always displace the *important* ones and since wars are always urgent (because life itself is at stake) the very important and necessary fight against the global phenomenon of AGW takes a back seat ... when it is not definitively forgotten.

If humanity does not significantly reduce —or, preferably, annul— the military academies of different nations and prevent generals from being part of the select groups that make the most important

⁴ Robert Proctor is a professor of History of Science at Stanford University and wrote, in 2008, the book *Agnotology. The Making and Unmaking of Ignorance*.

⁵ "Now, scientific evidence on effects of smoking. Much milder Chesterfield is best for you!"

decisions, humanity will not be able to build the planetary consciousness that is demanded to effectively fight against AGW.

The militia is a total institution and, as such, is absolutely opposed to democracy. An army could never be democratic. Only one should take all decisions. The task of others is simply to obey. Therein lies its efficiency and its enormous power ... against the planetary consciousness and the harmony of humanity.

In a world where urgent wars dominate and important climate change mitigation takes a backseat, inaction is a necessary consequence.

4.3 The democratic farce

The West likes to call itself “democratic” and the “defense of democracy” has been a flag in more than one international conflict. Those of us who live “in democracy”, however, know too well what, in most cases, it has become a mere marketing exercise where one can even count what it “costs” to win an election, since Votes are bought and, regardless of the quality of the “platform” of the candidate in question, if the right amount is invested, operators can make virtually anyone to win the election.

We should never have forgotten what Aristotle mentioned centuries ago: *Democracy* is the degraded version of the *Republic*. Let us remember that Aristotle, in chapter III of his *Politics*, indicates that the difference between a good and a bad government lies in the fact that it works for the good of all and not only for that of the king (tyranny), a minority (oligarchy) or a majority (democracy). In a *Republic*, rulers are expected not to operate in a factional manner and to truly seek the well-being of all citizens.

What Thomas Hobbes maintained in his *Leviathan* was not too different: to overcome the stage of wars of all against all, it is necessary that there be a Leviathan that is the only one with “free exercise of force” and that “works for the common good.” The Leviathan, by setting limits on “individual interests” in favor of the common good, is a key element of social peace and, in all cases, its task is to limit the worst human instincts: the desire for dominance, greed, avarice.

Establishing a republican, aristocratic or even monarchical government —but in the sense in which Aristotle or Hobbes defined it, that is, one where one governs not for the well-being of one, a group or the majority, but for the good of all—, should be an urgent task for all nations on earth. Only governments that are truly concerned about the future well-being of their fellow citizens will be able to establish the agreements that humanity urgently requires to stop the looming civilizational collapse. And since truly republican governments are far from being the majority, most of humanity remains inactive, resting in their comfort zone ... until collapse breaks out.

4.4 The corporate boom

The fourth reason that, from our reading, explains human inaction in the face of AGW is the main element of the economic model prevailing in the world today: the corporate boom.

For more than a decade we have known —thanks to the brilliant study *The Network of Global Corporate Control* by Vitali, Glattfelder and Battiston (2011)— that, today, the true owners of the world are not national governments but a handful of companies: Only 147 large corporations own 40% of the world's GDP ..., and 700 of them own 80% of the GDP.

In all corners of the world, corporate capital dominates and imposes fashions, tastes and even eating styles. And everyone loves that. The always beautiful, modern and clean corporations shield us and that prevents us from noticing their true nature: they are the ultimate invention of human greed, they constitute true economic predators (Klein, 2002).

Corporations have not only appropriated capital, but they are also responsible for the decline in workers' rights, the attack by States against their citizens and the establishment of a legal system that favors them.

As Bakan (2004) reminds us, a corporation is a “legal person”, that is, an individual with full rights and obligations: it can acquire goods, hire workers, obtain loans, establish demands and respond to them, it can increase its assets and even go bankrupt... although it cannot go to jail. The corporate “legal person” makes every capitalist's dream come true: carrying out ventures without fear of the lawsuits that any error could generate: the corporation allows the capitalist to enjoy limited liability, that is, in fact, it makes him lose responsibility.

The corporation can be called the masterpiece of the neoliberal system: it generates enormous amounts of capital for its investors and makes their dream come true by achieving the increased and quickest possible return on the invested capital. And if the actions of a corporation produce the loss of human life or the destruction of ecosystems —externalities— the owners, that is, the investors, have no responsibility, only their managers or administrators can be blamed for the damages as is shown by the case of Bhopal (1984)⁶.

The dominant corporate world is, with the complicity of humanity, responsible for the devastation of the world.⁷

The corporate legal person was a very bad idea that will have to be withdrawn if we want humanity to overcome the obstacle of the AGW. It is essential that the legal figure of the *corporation* be dissolved and that all those that bear such a name be reconverted into *companies*, recovering responsibility in the process. Only in this way will humanity be able to defend itself from its (now) immense power and to effectively confront Anthropogenic Global Warming.

4.5 Anthropocentrism and its consequences

In a previous essay we indicated that anthropocentrism is nothing more than the expression, on a social scale, of narcissism and, consequently, has caused humanity to consider itself “created in the image and likeness of God”, “chosen people” and, even, separated from the animal kingdom “humans are not animals” (Tamayo, 2015, 2024). Such an idea extended its power to our living space, generating criminal geocentrism and even pathetic flat earthism. I call geocentrism “criminal” because we must not forget that on February 16, 1616, a group of theologians concluded that the idea of the sun being at the center of the universe and the earth rotated on itself “was stupid, absurd in philosophy and formally heretical for contradicting Sacred Scripture” (Alonso, 2016), which caused the persecution and condemnation of Galileo Galilei and, almost 16 years before —on February 17, 1600— the immolation at the stake of Giordano Bruno.

⁶ Let us remember that on the night of December 2 to 3, 1984, in Bhopal, India, there was a leak of methyl isocyanate, a substance that the Union Carbide company used to produce pesticides, which generated, according to official figures, more than 3,500 immediate deaths and another 15,000 who died in the following weeks. Another 50,000 —those severely affected— still suffer today from pulmonary fibrosis, asthma, blindness, tuberculosis, spontaneous abortions, neurological damage and asthenia. And those affected called “mild” number half a million. The Union Carbide executive who lived in India, Warren Anderson, paid a small bail after the accident, escaped to the USA and died in Florida at the age of 92 without ever setting foot in a court. The American government never accepted the extradition request requested by the Indian government. Almost 30 years later, only two Indian executives of the company were sentenced to 2 years in prison (but with the right to bail and they can also appeal so the trial will extend even longer). And, to make matters worse, the fines against Union Carbide were insufficient and paid late. Finally, in 1999, Dow Chemical acquired Union Carbide and, of course, denies any responsibility for what happened. The “legal person” who caused the deaths and damage simply disappeared. There is no longer anyone to sue. Cf. <https://www.europapress.es/internacional/noticia-condenan-dos-anos-carcel-directivos-union-carbide-20100607165943.html>

⁷ Tamayo (2021).

We know, however, that anthropocentrism is nothing more than a crazy reaction to the more than patent human weakness. As Dany-Robert Dufour (1999) indicates, the human being is a neotene, that is, a species that, like the axolotl and other amphibians, is born, grows, reproduces and dies without having reached maturity. Although it is true that human beings manage to reach physical maturity after childhood, psychological maturity, unfortunately, is prevented by religions, schools, armies and political leaders, which feed on human undervaluation.

Anthropocentrism is a type of ideology that denies the unity of Dasein⁸ with the world and, consequently, leads those who suffer from it to believe themselves superior to the other species on earth. Therefore, it is allowed not only to exploit nature but also to exterminate species that affect its interests. Anthropocentrism is the ideological foundation of extractivism and is a serious disease because, given that the world is inherent to us, by completely consuming a mineral or exterminating an animal or plant species we only affect our own world, that is, ourselves. Anthropocentrism, as a pathology of the mundanity of Dasein, presents itself in various forms:

- *Extractivism* refers to the abusive treatment of humanity with respect to its world: the pure and simple overexploitation of nature (of the biosphere, the hydrosphere, the cryosphere or the lithosphere).
- *Consumerism* is a behavior that the industrial revolution made possible and leads humans to acquire countless products, many of them unnecessary and that fill up the residences of the wealthiest.
- *Innovative arrogance* is, as its name indicates, a disease specific to a specific sector of the population: the innovative community, nowadays, the techno-scientific community. It refers to that behavior, promoted by irresponsible and greedy businessmen, who hire scientists to present them with technical solutions to their production problems. Innovative arrogance appears in scientists who fall into the game of such entrepreneurs and propose practical solutions without clearly knowing the effects that the proposed substances or processes could have.
- *Avoidance* describes a type of psychopathology that exists in those who, faced with specific threats (derived, for example, from global environmental change or the sixth mass extinction of species), choose to escape through cults, drugs, video games and other forms of "entertainment". Evasion allows us to live in comfortable alternative worlds... while the house burns down.
- The *saving desire* consists of a type of arrogance where, whoever suffers it, attributes a power that exceeds them and makes them say: "as a superior species I take care of the poor and injured earth." The reality is that we are nothing more than one of nature's species, its power exceeds us and, rather, we should learn to respect it. Because it exceeds human power, the desire to save usually leads to frustration and inaction because "nothing can be done" or "it is too complex." The narcissism of those who suffer from the desire to save prevents them from noticing that what is at risk is not life -nature- but themselves, that is, human civilization itself and, consequently, it is not about "saving another" but saving oneself.

The mentioned "pathologies of worldliness" do produce actions, but these either go in exactly the opposite direction to future well-being —the actions of extractivists, consumerists, or arrogant innovators— or they are of such short scope —those of the "saviors of the earth"—which even seem like a simulation. From our point of view, all these pathologies are at the root of the failure of the countless summits, colloquiums, COPs and other meetings that have been attempted to stop or, at least, mitigate AGW.

⁸ Following the teachings of Heidegger, we call *Dasein* that entity that "am in each case myself." (Heidegger, 1927:53).

4.6 The failure of schools and universities

Universities and educational institutes do not help to avoid the scourge either because they are completely taken over by overloaded curricula and very important for *a world without civilizational collapse*. The student, society's natural agent of change, is so busy keeping up with his multiple tasks and activities that he simply does not have the time necessary to dedicate to solving the problems of his world. His very urgent activities translate into inaction regarding the phenomenon of Global Warming. And the situation of his teachers is no different. It is then that we realize that neither the creators of the career curricula nor the directors of the universities and institutes believe that a socio-environmental crisis is approaching. And if they, generally well-informed and prominent academics, are not convinced of the seriousness of the problem... Why should we expect the general public to care?

The conclusion of this section is simple: the few awakened citizens are alone and, meanwhile, the phenomenon advances. The Paris Agreement has been exceeded since the temperature has already exceeded 1.5 degrees Celsius for 12 consecutive months. The owners of the ball –the corporations– are not interested in changing anything and citizens will only be able to recognize the problem when they are faced with it.

This civilization, we cannot but regret, seems doomed to collapse.

IV. EARTH FOR ALL'S PROPOSAL TO STOP COLLAPSE

In their recent analysis the new members of the Club of Rome –Sandrine Dixson-Declève, Owen Gaffney, Jayati Ghosh, Jørgen Randers, Johan Rockström and Per Espen Stoknes– published the essay *Earth for All. A survival guide for humanity*. This essay is the updated version of the study *The limits to Growth* prepared by the Club of Rome in 1972 –Donella and Dennis Meadows, Jørgen Randers and William Behrens III. Let us remember that these authors applied System Dynamics to review the future of humanity. Associated with the Professor of the Massachusetts Institute of Technology (MIT) Jay Wilson Forrester (1918-2016) –who developed the World One program, correlating various variables of our civilization– they proposed that if humanity continued consuming in the usual way (the scenario Business as usual or BAU) a civilizational collapse would occur shortly after the middle of this century. In the 2022 version, the authors of *Earth for All* apply the improved World One program and propose two possible scenarios: the first is entitled *Too Little, Too Late* and the second is *The Giant Leap*. The first scenario is catastrophic: in 2050 a socio-environmental collapse begins which, among other things, causes the population to be reduced by half in 2100. The second scenario suggests that the crisis can be overcome if humanity becomes aware of the coming socio-environmental problem and collaborates to face it, eliminates its differences and rich countries support poor ones with resources and technology. In the Giant Jump all nations perform five turnarounds:

- The *elimination of poverty*. For decades, the economic growth of rich countries has been accompanied by the push for fossil fuels. The world now requires a path to energy from renewable sources, agriculture to be regenerative and cities to be sustainable. This implies that the International Monetary Fund allocates at least one billion USD annually to poor countries in order for them to generate “green jobs.” The World Trade Organization must also ensure that “intellectual property rights” regarding energy from renewable sources and other technologies in the field are left behind to encourage their dissemination in poor nations.
- The *reduction of inequality*. In recent decades, inequality in the world has grown and the richest 10% keep more than 50% of global income. This generates dysfunctional and polarized societies. To avoid this, Earth for All proposes that all governments establish taxes so that the richest 10% of their societies do not keep more than 40% of the nation's income, as well as that they empower workers and their unions with the aim of improving their well-being.

- *Empowering women.* There are many regions of the earth where being born a girl is still a disadvantage, places where access to education and well-paid work are exclusive to men. Experience has taught that the Nordic European countries, with market economies that invest in gender equality and families, have the best well-being and development indices on the planet. Such nations have also shown that when women have control over their lives they choose to have fewer children. To advance this change of direction, it is necessary to increase access to education for girls and women, encourage them to occupy leadership positions, as well as establish widespread and egalitarian pension systems.
- *Use of regenerative agriculture.* The agro-industrial food production model that the Green Revolution bequeathed to us –full of agrochemicals and genetically modified seeds– although it is true that it prevented serious famines, is currently taking its toll on us. Modern agriculture and livestock farming far exceed planetary limits and are the main causes of greenhouse gas emissions. They are responsible for deforestation, the loss of biodiversity and the establishment of vast dead zones in rivers, lakes and seas. Advancing the practice of regenerative agriculture involves avoiding overconsumption and waste in rich nations and establishing sufficient supply chains in poor nations. Farmers and ranchers must adopt techniques that allow for healthier soils and seas, avoiding harmful subsidies. It is also necessary for the population to adopt healthy diets –significantly reducing the consumption of meat and everything that involves large emissions of greenhouse gases.
- *To carry out an energy transformation.* The 6th IPCC Report (2021) indicates that to maintain the average temperature of the earth below 1.5 °C, it is necessary to reduce greenhouse gas emissions by half in 2030 and eliminate them completely in 2050. To achieve such an objective implies, according to *Earth for All*, that emissions be reduced by half every decade starting in 2020. This is feasible given that the technologies are available, affordable and scalable. And they cost the same, or even less, than fossil fuels. All that is required is the political will. It is also necessary to redesign the processes and electrify everything possible, transfer technology from developed countries to poor ones and significantly increase (more than a billion US Dlls annually) in the improvement and implementation of renewable sources.

Thanks to all these actions, the risk of a runaway climate on Earth would be significantly reduced, as well as the associated socio-environmental crisis (Dixon-Declève, 2022: 50). Carrying out *the Giant Leap* scenario, unfortunately, seems quite unlikely. The other, much more feasible scenario is called *Too Little, Too Late*. Such a scenario establishes that, if the same dynamics that the world has carried out from 1980 to 2020 continue, both population and economic growth will slow down, employment will be lacking, trust in governments will decrease, humanity's ecological footprint and the loss of biodiversity will increase. In the coming decades, this scenario indicates, poverty will persist in most of the world and inequality will destabilize rich countries. Some of the Sustainable Development Goals (SDGs) will be achieved and this “will represent some progress in a world without planetary limits”, but, in general, there will be a dramatic increase in the Social Tension Index. This scenario does not establish an ecological or climatic collapse in this century, but the beginning of a social collapse after 2050. Such collapse will be a consequence of social division and ecological damage. This risk, the report indicates, will be particularly acute in those countries “poorly governed and with ecologically vulnerable economies” (Dixon-Declève, 2022: 35).

Unfortunately, it is highly unlikely that humanity will be able to take the necessary measures in time to stop the looming collapse.

V. RELEARNING TO BE HUMAN THANKS TO INDIGENOUS COMMUNITIES

It's not hard to imagine that when the first Sapiens were kicked out of the trees and forced to walk bipedally on the dangerous ground, they had to cooperate to survive. Since cooperation requires interhuman coordination, an increasingly precise and efficient language became essential. Consequently, only the most intelligent and collaborative prospered. In cooperation the life drive (the impulse to build increasingly larger units) is dominant. It was cooperation that allowed the first symbiotes⁹ to establish social institutions that increased solidarity. Among them we can refer to Potlatch (I am richer when I give more), Ubuntu (I am as others are) and Tequio collaboration ("today for you, tomorrow for me")¹⁰.

Tequio is a current practice in some Mesoamerican towns through which the inhabitants of a community commit themselves to solidarity with their fellow humans: both in the harvesting of crops and in the construction of buildings for the common good and even for the personal good. Thanks to this social technology, the poorest communities in deep Mexico have been able to cope with life and maintain enviable joy and confidence in their communities.

It is no different with *Ubuntu*, in this regard let us remember that this notion is part of the conceptual map of Zulu/Xhosa philosophy and is its way of saying unity with the other: "I am because we all are", "if everyone wins, I win", "everything mine belongs to everyone" (Rovira, 2015).

The *Potlatch*, finally, was a practice where, once a year and between ritual dances, the leaders of the different native peoples of North America gave away –or destroyed– their belongings. It was prohibited by the Indian Act of the USA and Canada of 1884 for going against the "capitalist spirit." In 1921 there were still around twenty indigenous people in prison for not complying with the mandate (Álvarez, 2017).

The respect for ecosystems and nature is also a remarkable cultural imprint in communal cultures, the best example was recently given by the Māori people¹¹, who were able to use the language of the invader, its law, and methods to recover the Whanganui River, the longest navigable river in *Aotearoa*¹² (New Zealand) from the United Kingdom (English Crown).

It was the "capitalist spirit" or, as we prefer to call it, "narcissistic" that caused the forgetting of their brotherhood to occur when the necessary separation of the first human clans occurred. Inequality and division soon appeared between people, as well as within each one of them – between whites and blacks or rich and poor. Immediately afterwards, wars over resources began and the other, who was previously the brother, the uncle, the nephew, became the different one, the foreigner and even the enemy. Finally, due to the comforts brought by the industrial revolution, *cooperative* institutions gradually became unnecessary and, in the end, fell into oblivion, which led to the loss of a good part of humanity¹³.

Education –necessarily repressive since the perversely polymorphous human requires his drives to be limited to live in society¹⁴– soon exacerbated the ravages of the civilizational model based on competition. Thanks to the studies of Neill (1974), Freire (1980), Foucault (1990) and Miller (1980), we know that *competitive* modern education can be a source of much suffering: it turns the educational act

⁹ Riechmann (2022).

¹⁰ Tamayo (2021: 21).

¹¹ https://en.wikipedia.org/wiki/M%C4%81ori_people

¹² <https://en.wikipedia.org/wiki/Aotearoa>

¹³ We qualify this statement because many indigenous peoples –such as those of Bhutan, the Amazon and some of Latin America– continue to preserve these ancient practices.

¹⁴ Freud (1976/1930).

into a sadistic and castrating practice. In its desire to generate individuals capable of carrying out complex activities —competent professionals— authoritarian education established rigid procedures not only for selection and training but also for evaluation. The wonderful childhood curiosity and taste for knowledge were drowned in norms, rules and punishments applied to children and young people “for their own good.” In such an educational model, not only is the desire to know lost, critical capacity and creativity are also excluded¹⁵. In authoritarian education the libertarian desire: “to become who one is” (*Werde was du bist!*)¹⁶ is left out of the picture and tends to generate slaves, mere robots capable of mechanically carrying out the actions for which they were trained.

The “competitive” scheme was also reflected in the economy: the other became someone despicable, a competitor or a stupid consumer to be lured with deception to defraud them. Then greed, dispossession, capitalism, compound interest and, finally, corporations appeared.

As we indicated before, the modern corporation is a type of enterprise created with the aim of evading responsibility. The modern transnational corporation is not a mere commercial legal figure, it is, as indicated in a previous study¹⁷, a kind of Alien —an unconscious, incomprehensible, devastating and deadly “extraterrestrial being”— that threatens everyone because it is one of the main expressions of the death drive. Their only objective: the recovery, increased and as quickly as possible, of the invested capital means that they never worry about the sustainability of existing resources or the damage to the regions where they are located (the “externalities”); They don't even care about their consumers and are capable of offering them products that harm their health or processes that make the places where they live uninhabitable.

Dissolving the legal figure of the corporation —to reconvert *corporations* into *companies with responsibility*— would be a more than efficient measure in the right direction, the *demilitarization* of states and the recovery of unity with each other (*Mitsein*) and the world (*In-der-Welt-sein*), too, since they would promote cooperation, solidarity and symbiosis with our natural environment.

The window of opportunity to stop the worst effects of AGW is still open, it is up to us to achieve it.

VI. CONCLUSION

The reasons for human inaction on global warming are a series of intertwined variables: induced ignorance, militarism, democratic farce and anthropocentrism, all of which allow the unrestricted exploitation of nature and are leading humanity to a socio-environmental crisis of such dimensions that make it very likely that, as indicated by the Club of Rome (Dixson-Declève, 2022), a Civilizational Collapse will occur shortly after the middle of this century. It will be our children and grandchildren, as well as many other species that have accompanied humanity's stay on Earth, who will pay —and dearly— for the transgenerational tyranny currently in force.

At this moment everything seems to indicate that we will not be able to stop the collapse in time and, consequently, we will bequeath to our descendants a depredated world with an *unstable climate*.

Cuernavaca, México, 31 de marzo de 2023.

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ABSTRACT

The main objective of the study was to examine the widening gap between frequent changes in the institutional architecture and effectiveness of municipal solid waste management in the City of Harare, Zimbabwe's capital city and largest urban metropolis. The study was conducted between December 2021 and August 2022, using a combination of qualitative and quantitative methods, including document review, key informant interviews, field observations, and a survey of solid waste collection in selected low, middle, and high-income residential areas. Significant developments in solid waste management were used to update the study between mid-2022 and the first quarter of 2024. Since its independence in 1980, Harare has relied mainly on traditional solid waste management approaches, characterized by linear waste flows from waste generators to landfills. This was despite nine institutional changes in the same period (one every four years), encompassing variations of centralized municipal management, ad hoc private sector participation, and interventions by central government. Neglect of sustainable waste management practices, such as decentralization, formalization of the informal waste sector, and circular economy principles, is contributing to serious environmental challenges in the City.

Keywords: municipal solid waste management, disjuncture, waste governance, institutional change, sustainable integrated waste management.

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Keywords: municipal solid waste management, disjuncture, waste governance, institutional change, sustainable integrated waste management.

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I. INTRODUCTION

Globally, municipal solid waste (MSW) is recognized as a serious developmental challenge. To this end, the United Nations (UN) adopted Sustainable Development Goal (SDG) 11 (Sustainable Cities and Communities), more specifically indicator 11.6.1 formulated as the proportion of urban solid waste regularly collected and with adequate final discharge out of total urban solid waste generated by cities (Loots, 2023; Yuan et al., 2023). The primary goal of municipal solid waste management is to reduce

and eliminate adverse impacts of waste on human health and the environment, and in so doing improve quality of life and socio-economic development (Mali and Patil, 2016). While municipal solid waste is generally defined as solid or semi-solid materials, excluding hazardous wastes and wastewater, which is discarded by residents, businesses, and other institutions in urban areas (UN-HABITAT, 2018), it is, however, perceived by different sections of society, and this has implications on how it is managed. For instance, some engineers view waste as materials that interfere with engineering infrastructure and systems, anthropologists regard it as material for studying people's consumption culture, and industrial ecologists tend to view waste as a right thing in a wrong place, as it can be a source of energy, for example (Vergara and Tchobanoglous, 2012). For many local authorities, waste is a valueless commodity that must be consigned to landfills while waste pickers, in contrast, tend to regard it as a source of income and livelihoods (Vergara and Tchobanoglous, 2012). In many developing countries, the perception that waste is valueless is dominant, if not by definition but by practice. This explains why municipal solid waste is a greater challenge in developing countries, including Sub-Saharan Africa, even though the amount of waste that is generated is comparatively lower than in developed countries (Asefi et al., 2020).

Sub-Saharan Africa faces serious municipal solid waste management challenges. Between 2015 and 2020, approximately 65-67% of municipal solid waste generated in SSA was collected and managed in controlled facilities (Adedara et al., 2023). This was attributed to inadequate waste collection and disposal infrastructure, lack of awareness and public education, insufficient funding, weak legislation, and poor enforcement, as well as lack of appropriate skills among the municipal workforce (Adedara et al., 2023). Some experts have argued that poor solid waste management in Sub-Saharan Africa is a reflection of poor waste governance (Godfrey et al., 2019). Policy-related barriers were found to account for 75% of solid waste management challenges (Aparcana, 2017). Broader socio-economic challenges are a contributing factor to poor municipal solid waste management. Out of the 27 countries in the world, which are classified as low-income, 24 are found in Sub-Saharan Africa. Despite remarkable economic growth in the region since the turn of the new millennium, the growth has not been robust enough to finance the requisite social services like solid waste management (Pelizzo et al., 2018). A rapidly growing population is worsening the situation. For example, Sub-Saharan Africa population is projected to account for approximately 60-70% rise in population by 2050 (AfDB, 2016; Lohnert, 2017). In the same period, the African continent will account for the largest proportion of world population living in urban areas, and will also account for the largest proportion of world population living in areas with limited and non-existing waste management services, such as in informal settlements (Overdorf, 2019; UN HABITAT, 2018). Sub-Saharan Africa accounts for the highest proportion of people living in informal settlements in the world (Overdorf, 2019).

Zimbabwe, like many other countries in Sub-Saharan Africa, is facing serious municipal solid waste management challenges. Between one and two thirds of solid waste generated in urban areas is not collected, is dumped illegally or burnt, a situation worsened by minimal recycling (Chirisa, 2014; GOZ, 2014). For example, in Harare, Zimbabwe's capital city and largest urban metropolis, only 9.6% of municipal solid waste is recycled (Nhubu et al., 2020). There is a rich literature on MSWM challenges in urban areas of Zimbabwe, particularly in Harare. The literature can be placed in three broad categories. The first category deals with waste generated in terms of sources, type, and quantity. The majority of the literature discusses solid waste generated at household level (see for example (Chikobvu and Makarati, 2011; Mandevera, 2021; Mandevera and Jerie, 2018; Mangizvo, 2007; Manyanhaire et al., 2009; Shabani and Jerie, 2023), and to a lesser extent, in industries, educational and other institutions (Chatira-Muchopa et al., 2019; Shabani and Jerie, 2023). The average daily waste generated per capita in Harare was estimated to be 0.4 kg (Kwenda et al., 2022a), which is comparable to 2.7 kg per household per day reported for Chinhoyi Town (Musademba et al., 2011). A large proportion of solid waste is organic, mainly made up of food leftovers (Mandevera and Jerie, 2018).

While the organic waste is biodegradable and suitable for thermochemical waste-to-energy conversion, its potential remains largely unexploited in Zimbabwe (Makarichi et al., 2019). Other types of waste include plastic and paper (Chikobvu and Makarati, 2011), medical waste (Nyakatswau et al., 2022) and electronic waste (Mandevere, 2021; Mutsau et al., 2015). Lack of and/or inadequate data has also been reported to be compromising effective solid waste management (Allesch and Brunner, 2014; Nhuhu et al., 2020). Similar results were obtained in other Zimbabwean cities such as Bulawayo, Chinhoyi, Gweru, Masvingo and Mutare (Mangizvo, 2007; Manyanhai et al., 2009; Mudzengerere and Chigwenya, 2018).

The second category of the literature discusses solid waste collection and disposal challenges. Urban local authorities, which are legally mandated to manage solid waste (GOZ, 2014), are failing to cope (Kwenda et al., 2022a). This has given rise to a ‘throw-away’ culture (Chirisa, 2014), characterized by illegal dumping, burning, burying/composting of waste (Chatira-Muchopa et al., 2019; Mandevere and Jerie, 2018; Mangundu et al., 2013; Musademba et al., 2011; Tsiko and Togarepi, 2012). Urban local authorities lack financial, human, and material resources to undertake effective solid waste management. For example, the City of Harare operates a fleet of 33 refuse trucks instead of 120 (Kwenda et al., 2022b). Using Network Analysis Techniques, Kwenda et al. (2022b) identified drivers and outcomes of household waste management in Harare (Table 1). Drivers were defined as issues that influence other issues more than they are influenced themselves while outcomes are vice versa (Kwenda et al., 2022a). The designation of drivers and outcomes can be contested. For example, it is not clear why economy was designated an outcome and not a driver, and why street vendors were designated both as driver and an outcome instead of just a driver.

Table 1: Classification of key household waste management issues into either drivers or outcomes in Harare, Zimbabwe

Waste management issue	Driver/Outcome
1. Uncollected waste	Driver/outcome
2. Waste collection efficiency	Outcome
3. Illegal waste dumping	Outcome
4. Economy	Outcome
5. Financial capacity	Driver
6. Workforce capacity	Driver
7. Waste data	Outcome
8. Waste volume	Outcome
9. Street vendors	Driver/outcome
10. Planning and monitoring	Driver
11. No engineered landfills	Driver/outcome
12. Waste collection pressure	Driver
13. Waste collection frequency	Outcome
14. Unemployment rate	Driver
15. Technical capacity	Outcome
16. Waste collection vehicles	Outcome
17. Vehicles maintenance	Outcome
18. Socio-economic status	Driver
19. Vehicles breakdown	Driver/outcome
20. Population	Driver/outcome

Source: Adapted from Kwenda et al. (2022a).

The third and last category discusses different aspects of solid waste governance, albeit to a limited extent. Poor articulation and enforcement of policies and laws, as well as poor community participation, are identified as important challenges (Mandeverere and Jerie, 2018; Mangundu et al., 2013; Nyakatswau et al., 2022). There are suggestions that these challenges are symptomatic of wider governance challenges as reflected by central government interference in local government affairs (Jonga and Chirisa, 2009; Mapuva, 2014; Muchadenyika and Williams, 2016). Central government, on the other hand, contends that it is discharging its mandate of providing policy direction, a “mandate” which it has exercised many times since independence in 1980 (see below). This paradox of frequent changes in the institutional architecture and poor solid waste management has not attracted the attention of many researchers in Zimbabwe (Muheirwe et al., 2022). This paper aims to fill this gap.

Institutional change refers to the underlying social rules or norms that define how societal functions are structured and governed, which is not the same as organizational change that focuses on process design, teamwork and leadership in the organisation (Halal, 2005). In this study, institutions are understood as humanly devised constraints that structure political, economic and social interactions and are “rules of the game” and can be formal or informal (North, 1990). This paper focuses on formal institutions, which are mandated by law to manage solid waste. Informal institutions are, however, not excluded from the discussion of the institutional waste management architecture. Institutional waste management architecture refers to solid waste management arrangements between central government (which provides policy direction supported by appropriate legislation), local authorities (responsible for bylaws governing regulation and implementation of waste) and ratepayers who are supposed to benefit from waste management practices. The focus of the paper is on how the institutional changes have affected the effectiveness of solid waste management in Harare. This is an important line of enquiry because since independence in 1980, municipal solid waste management in Zimbabwe in general and Harare in particular, has undergone significant changes. After reasonable service provision in the first two decades of independence, the situation considerably deteriorated. The deterioration coincided with an unprecedented economic crisis, due to poor economic policies and sanctions imposed by the West because of allegations of governance transgressions by the ruling party, the Zimbabwe African National Union Patriotic Front (ZANU PF), which has been in power since independence. The period also coincided with the opposition parties taking over control of practically all urban municipalities from ZANU PF.

The paper examines the disjuncture between approaches to municipal solid waste management and institutional changes in Harare between 1980 and 2022. Rather than focusing on the disconnect, which implies a lack of communication or understanding between people or groups, the paper focuses on disjuncture, referring to the lack of connection or coherence between different elements or parts (of municipal solid waste management) because of strategic interests and contestations (<https://comparewords.com/disconnection/disjuncture>). Specifically, the paper assesses the effectiveness of solid waste management approaches against the backdrop of frequent institutional changes. Examining the disjuncture and finding its resolution is important. Municipal solid waste management in Harare, and other areas in Zimbabwe, has been discussed in two silos: a) empirical accounts of poor waste collection and b) poor governance as illustrated by central government intervention/interference. By simultaneously examining waste collection practices and solid municipal solid waste governance, this paper offers a more complete exploration of cause-and-effect relationships in municipal solid waste management, not only not only in Harare but also in other urban areas in Zimbabwe.

The paper is organised as follows. The next section presents a literature review of municipal solid waste management approaches in Sub-Saharan Africa, focusing on both technical and institutional aspects, as a backdrop to discussing the effectiveness of different approaches that the City of Harare has put in

place. Thereafter, in Section 3, is the methodology of the study. Section 4 presents the results and discussion of the study. Section 5 presents conclusions of the study.

II. APPROACHES TO MUNICIPAL SOLID WASTE MANAGEMENT: A LITERATURE REVIEW

The literature review on approaches to municipal solid waste management in this section is organized around three main themes. The first discusses differences between traditional and more environmentally friendly approaches, commonly referred to sustainable solid waste management. This is followed by a discussion of prospects for a circular economy in Sub-Africa. The third and final theme discusses different types of institutional arrangements for municipal solid waste management, focusing on those that may be most suited for a developing country like Zimbabwe.

2.1 Differences between traditional and sustainable municipals solid waste management

Municipal solid waste management refers to collection, transfer, processing, recycling, resource recovery, treatment, and disposal of solid waste in urban areas (Mali and Patil, 2016), and is composed of six main components (Table 2).

Table 2: Description of solid waste management stages.

Component	Description
1. Waste generation	Encompasses activities that produce waste that is considered no longer useful
2. Onsite handling, storage, and processing	Activities at the point of waste generation, which facilitate easier waste collection
3. Waste collection	Includes activities such as providing waste receptors, and accumulating waste in locations from where it is collected *
4. Waste transfer and transport	Moving waste from local waste collection points to waste disposal or processing sites
5. Waste processing and recovery	Facilities, equipment, and techniques used to recover reusable or recyclable materials from waste streams
6. Disposal	Disposing waste materials in locations such as landfills or conveying them to waste-to-energy facilities

Source: www.liveabout.com/an-introduction-to-solid-waste-management-2878102

*While transportation is involved, this is typically not the main stage of waste transportation.

The components are emphasized and arranged differently in traditional and sustainable solid waste management approaches (Figure 1). As can be seen from the figure, the traditional approach conceptualises municipal solid waste management in linear terms focusing on end-of-pipe solutions, such as disposing waste in landfills and incinerators, which has serious negative environmental and health impacts. On the other hand, sustainable solid waste management minimizes environmental impact of waste while maximizing resource use efficiency through incorporation of economic, environmental and social principles (Marshall and Farahbakhsh, 2013; Morrissey and Browne, 2004; Satyro et al., 2017).

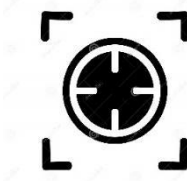
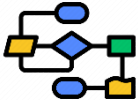
DIMENSION	1. TRADITIONAL SOLID WASTE MANAGEMENT	SUSTAINABLE SOLID WASTE MANAGEMENT
 Focus	o Waste collection and disposal without considering broader impact on environment and public health	Integrates environmental, social, and economic aspects
 Process flow	Waste flows linearly from waste generators to landfills or incinerators, with limited emphasis on resource recovery	Comprehensive view of the entire waste system, including collection, disposal, and resource recovery
 BENCHMARKING	o Minimal benchmarking	o Three key benchmarks: public health and collection, environment and disposal, and resource recovery
 Data	Not based on accurate data	Reliable and accurate data is crucial
 Governance	Tends to be reactive than proactive	Incorporates stakeholder inclusivity, financial sustainability and robust institutions
 Informal waste sector	Excludes informal waste sector	Recognizes role of informal sector and its contribution to recycling rates and cost savings
 Challenges	Inefficiency, inadequate data, and lack of effective governance	High capital, material and human investment

Figure 1: Graphic comparison of traditional and sustainable solid waste management.

Sometimes sustainable waste management is divided into Sustainable Waste Management (SWM) and Integrated Solid Waste Management (ISWM). SWM focuses on minimizing environmental impact of waste through its life cycle by balancing ecological, social and economic considerations while ISWM

refers to a strategic approach to managing solid waste sustainability and covers all aspects of waste management from generation to disposal, emphasizing resource efficiency (Wilson et al., 2013). There are several tools that are used to operationalize optimize sustainable solid waste management (Table 3).

Table 3: Tools/principles that can be used to operationalize sustainable solid waste management.

Tool/principle	Description/Focus
Waste hierarchy	Used to determine the best course of action for waste management, and includes five stages (prevention, reuse, recycle, recovery, and disposal of final waste)
3Rs	Incorporates three principles: reduce (minimizing amount of waste generated), reuse (finding new ways of using waste) and recycle (processing suitable waste)
Life Cycle Assessment	Assesses environmental impact of a product or service throughout its life cycle, from raw material extraction to waste disposal
Zero waste	Eliminates waste by designing products and systems that prevent or reduce waste generation, reuse or recycle materials, and minimize environmental impacts
Waste-to-Energy	Conversion of waste into energy, such as electricity, heat or fuel
Composting	Decomposing organic waste into a nutrient-rich soil amendment
Extended Producer Responsibility	Waste generators are responsible for the environmental impact of their activities/ products
Pay-As-You-Throw	Pricing system that charges households and businesses for waste they generate
Cleaner production	Preventive, integrated, and continuous strategy for modifying products and processes to enhance efficiency, to improve environmental performance, and reduce costs through optimising use of raw materials, energy and water

Sources: (Ferrari et al., 2016; Marshall and Farahbakhsh, 2013; Morrissey and Browne, 2004; Saja et al., 2021).

In developing countries such as Zimbabwe, where the traditional solid waste management approach is dominant, the principles/tools are either are deployed by default (such as compositing), are in their infancy, or are absent altogether due to a combination of lack of appropriate investment, technologies and supportive legislation and policies (Makarichi et al., 2019; Shaban et al., 2022). There are, however, steps being taken to put in place sustainable and integrated solid waste management. For example, the Government of Zimbabwe has developed the Zimbabwe's Integrated Solid Waste Management Plan (GOZ, 2014).

2.2 Solid waste management and circular economy

In general, Sub-Saharan Africa lags behind the adoption of solid waste management practices that use circular/green economy principles (Debrah et al., 2022; Feleke et al., 2021; Folarin, 2022). An exception to the rule is Rwanda, which recently launched its National Circular Economy Action Plan and Roadmap (Republic of Rwanda, 2022). Out of the 17 policy intervention areas, five are directly related to solid waste and contribute to a circular economy. These include valorization of organic waste and construction and demolition waste, reduction of postharvest losses, establishing waste collection and centres , systemic data collection system, and national regulations to guide waste characterization and treatment (Republic of Rwanda, 2022).

There have also been regional efforts to promote circular economy in Africa. One such initiative is the Africa Circular Economy Facility. Its objective is to mainstream circular economy principles through creation of institutional frameworks that, among others, promote private sector participation in the transition towards circular economy in recognition that a circular economy can generate an annual revenue of USD8 billion per year to the continent (<https://www.afdb.org/en/topics-and-sectors/topics/circular-economy/africa-circular-economy-facility-acef>). There is, however, a recognition that the transition faces several challenges. These include lack of supportive policy, legislative/regulatory and fiscal instruments, limited public awareness, limited private sector participation and public and private sector partnerships, and unclear communication. Apart from governance-related challenges, there are also technical shortcomings such as inadequate and outdated waste management systems, very low level of waste recycling, and standardization and implementation of compostable and biodegradable materials.

2.3 Institutional arrangements for municipal solid waste management

Historically, and this remains true in many developing countries, municipal solid waste in urban areas is managed centrally by the responsible municipality. The centralised approach does not mean take-over of control by central government. It refers to the fact that the municipality is responsible for all solid waste management aspects, including operational functions (collecting, transporting and disposal of waste) and regulatory functions in the form of local rules. In Zimbabwe they are known as bye-laws, which are recommended by the municipality and approved and gazetted by central government. While the centralized system has the advantage of economies of scale, it tends to suffer from inefficiencies, limited public funds and limited technological innovativeness. For these reasons, alternative approaches have been sought, such as privatization, decentralization (which includes stakeholder participation), and formalization of informal waste collection.

Privatization of municipal solid waste management arose as part of a liberal agenda driven by the IMF/World Bank, which promoted 'efficient' private sector instead of what was considered to be an inefficient, incompetent and sometimes corrupt public sector. It involves contracting private players to take responsibility for technical, financial operation aspects, for a specified time period called a concession (Chitonge, 2011; Lawal et al., 2024). Privatization of solid waste management was implemented in Kampala. Privatization of solid waste management was tried in some cities in Sub-Saharan Africa such as Dar es Salaam, Tanzania and Johannesburg, South Africa where waste collection and transportation was privatised (Cheng and Urpelainen, 2015; Fernando and Zutshi, 2023; Fidelis et al., 2023; Samson, 2007). However, scholars argued that private players cannot rescue SWM in developing countries without the respective government support and engagement (Cheng and Urpelainen, 2015; Samson, 2007).

In some cases, the envisaged benefits of privatisation/commercialisation of public services do not materialise. Consequently, privation/commercialisation of social services has been discontinued, resulting in re-municipalisation of services (Chung and Lo, 2008). Decentralization is reported to have a lot of potential, especially in developing countries (Ahsan et al., 2014; Kadafa, 2016). It is more responsive to local needs and conditions, more cost-effective (for example it reduces distances travelled by waste collection vehicles and the associated, operation and maintenance costs), reduces greenhouse gas and other negative environmental impacts, and allows greater participation by the private sector and communities (Madhukumar, 2022).

Decentralisation involves delegating power and responsibility for waste management to local authorities, communities, and other stakeholders (Nhubu et al., 2020). This can be achieved by household backyard composting, community level and industrial scale anaerobic digestion, composting

and anaerobic co-digestion of the organic fraction and dewatered sewage sludge, source separation for material recovery, establishment of waste transfer stations, citizens drop off centres, buy-back centres and thermal treatment facilities for energy recovery (Nhubu et al., 2020). Zimbabwe's Integrated Solid Waste Management Plan cites decentralisation as an important component of municipal solid waste management (GOZ, 2014).

Normalization of the informal waste sector has been reported to be effective because of its flexibility and inexpensiveness (Aparcana, 2017). Under the arrangement, formal and informal waste management interact. Informal waste collection provides a free service to the municipality (and actually subsidizes the cities) in which they operate. If arranged properly, it can be a win-win situation. The urban poor can secure their livelihoods from collecting and recycling waste while the environmental challenges are addressed. The exact arrangements differ from city to city. In Delhi, in India informal workers collect waste from households and transport it to temporary storage units, from which private companies and the municipality provide secondary collection (Bhawal Mukherji et al., 2016). In Bamako, Mali, informal microenterprises use donkey-drawn carts to collect 300,000 metric tons of waste per year, covering 57% of the city, and deliver it to secondary collection sites in a private-to-private arrangement (Vergara and Tchobanoglous, 2012). In Bogotá, Colombia, informal collectors remove materials from bags of waste that would otherwise be sent to landfills and reroute materials from a path of waste into a recycling chain (Parra, 2020; Vergara et al., 2016). This shows that robust institutional arrangements should be in place to facilitate informal waste collection. However, voluntary community-based management may collapse as volunteers may choose to withdraw their services for one reason or another.

III. METHODOLOGY

3.1 Study Area

The study was conducted in Harare, the capital city of Zimbabwe, focusing on residential areas, which are located around the Central Business District, referred to in the map as City Centre and Avenues (Figure 2). Residential areas in Harare, as is true across country, are categorised into low, medium and high density, a nomenclature that was adopted after independence in 1980. It refers to the size of the residential stand on which the house is built. Stands in high-density areas average about 300 m², while in medium-density areas the size is 400-700 m² and are bigger than 700 m² in low-density areas. The categorization reflects the socio-economic status of the occupiers -household income decreases from low to high-density areas.

High-density residential areas are made up of formerly black residential areas, which accommodated the majority black population, which lived in cramped and poorly served areas, and includes similar areas created after independence (Tsiko and Togarepi, 2012; Zinyama, 1995). Low-density residential areas are mainly composed of former white suburbs, which accommodated a white minority population living in well-served areas and in similar other areas developed after independence (Cumming et al., 1993). Medium-density residential areas fall between the two. Municipal services are cross-subsidized. Residents in more affluent suburbs pay more than those in less affluent suburbs.

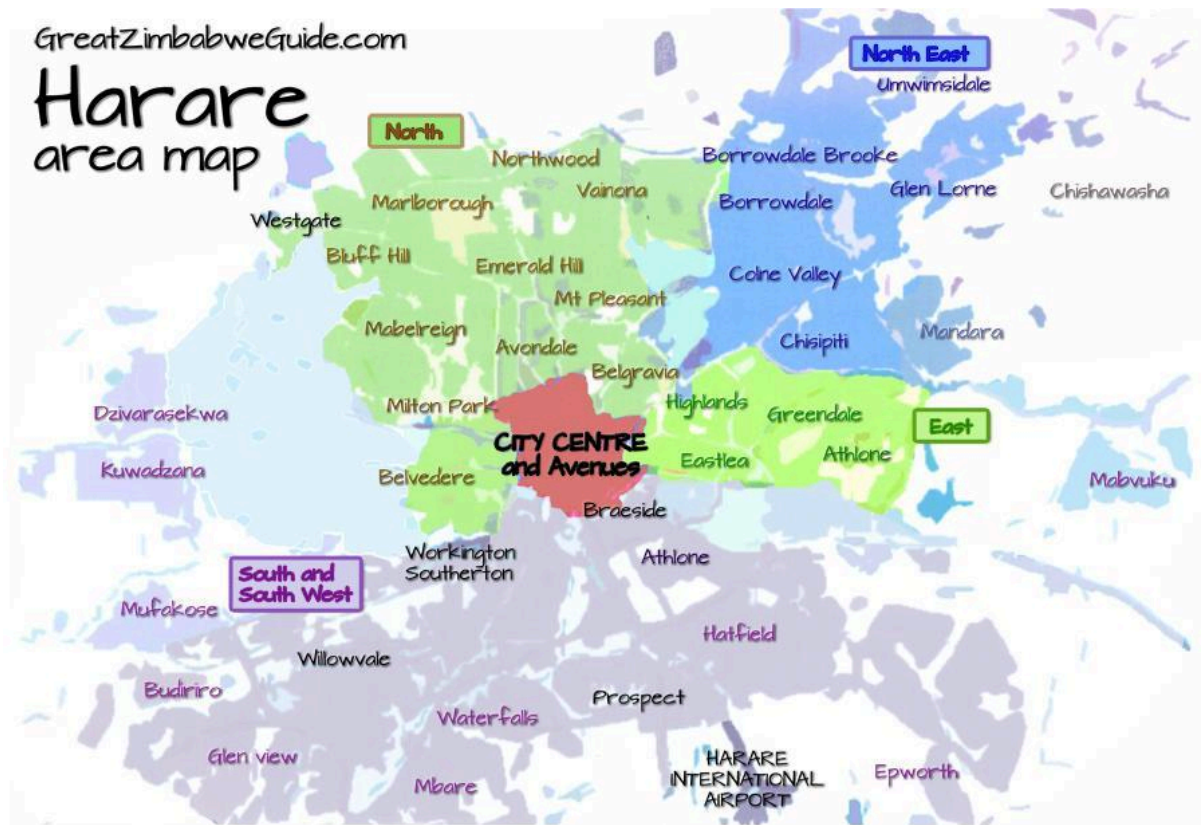


Figure 2: Map of Harare showing spatial extent of residential areas (Source: google maps)

Since independence in 1980, the size of the population of Harare has quadrupled from about 616, 000 to an estimated population of 2, 427, 431 by 2022 (ZIMSTAT, 2022). This increase has resulted in the establishment of new residential areas some of which have minimal services under the parallel development where people are allowed to build houses without full provision of services, as is the standard practice. There are also informal settlements without social services at all. However, social services have deteriorated even in formal settlements. This situation has resulted Harare being the rated among the worst African cities as far as solid waste management is concerned (Kwenda et al., 2022b).

Solid waste management in the City, just like other basic social services, is under the political control of the Harare City Council, made of 46 councillors elected from the 46 wards. From these is elected a mayor and various committees. Administrative functions are performed by the City of Harare (under the control of the Council), made up of the following departments: Town Clerk, Department of Works, Finance Department, Harare Water, Health Services, Department of Housing and Community Services in which is found the Division of Waste Management.

The City collects and disposes waste at Pomona and Golden Quarry dump sites. The Pomona landfill site is located 12 km north of the City centre while the Golden Quarry landfill lies 7 km west of the city centre. Pomona is the main dumpsite of the City.

3.2 Data Collection and Analysis

The study was undertaken between December 2021 and June 2022. First, a historical assessment of the solid waste management approaches and institutional arrangements was undertaken from 1980 and 2022. This was followed by examining solid management practices, which included adherence to waste

collection schedules and stakeholder views about the effectiveness of solid waste management in areas serviced by the City and private sector players. The study was updated to include major changes regarding waste management in the City between mid-2022 and the first quarter of 2024.

3.2.1 Assessing municipal solid waste management approaches

Secondary analysed data and protocols for solid waste management obtained from the City of Harare were examined to obtain a historical overview of the approaches and in terms of institutional changes relating to responsibility for solid waste management from independence in 1980 to 2022. Key Informant interviews were held with five key City of Harare personnel of the Waste Management Division, made up of a waste superintendent, two waste officers and a waste collection truck driver. The interviews complemented document review. Data was analysed qualitatively by organising into themes (centralisation, decentralisation, informal waste collectors and privatisation etc), eliciting meaning, and presenting conclusions from collected data (Jnanathapaswi, 2021).

3.2.2 Current solid waste management practices

Multi-stage sampling was used to select suburbs to study current solid waste management practices. First, suburbs representing high, medium and low-density areas were selected to capture the operations of private waste collection entities to enable comparison with the city's effectiveness of waste collection. Budiriro and Warren Park represented high-density suburbs, Belvedere and Marlborough – medium-density areas, Helensvale, and Mount Pleasant Heights represented low-density areas. Budiriro was the epicentre of cholera outbreak in 2018, a reflection of poor solid waste management. Warren Park, like Budirio, was established in the 1970s, but with less cases of cholera was chosen for comparison.

Effectiveness of municipal solid waste collection was assessed in terms of the presence of a waste collection schedule, adherence to the schedule frequency and the degree of effectiveness from observations and the degree this satisfied stakeholders. We employed a rating scoring system (1 - inadequate, 2 - poor, 3 - satisfactory, 4 - good and 5 - very good) to evaluate the effectiveness of waste management services by interviewing 60 respondents from low, medium and high-income suburbs (Table 4). The numbers were low because of poor availability of respondents.

Table 4: Number of respondents in low, medium and high-income suburbs of City of Harare

Income status/Suburb	Number of respondents
LOW DENSITY (HIGH INCOME)	
Helensvale	10
Mount Pleasant Heights	10
MEDIUM DENSITY (MEDIUM INCOME)	
Belvedere	8
Marlborough	12
HIGH DENSITY (LOW INCOME)	
Budiriro	7
Warren Park	13
Total	60

Responses from the survey were complemented by Key Informant interviews, in the residential areas and observations on waste management in each suburb.

Observations of current SWM practices were done over a seven-day cycle between March and August 2022 in residential areas in the six suburbs.

3.2.3 Updating solid waste management after the study period

Major developments, carried in the media and government gazette regarding solid waste management in the City of Harare after the study period, were captured and analysed. These related to mid-2022 and the first quarter of 2024.

IV. RESULTS AND DISCUSSION

4.1 MSW management approaches and institutional arrangements

Table 5 shows that since Zimbabwe’s independence in 1980, the City of Harare has predominantly relied on traditional solid waste management approaches, specifically, Stages 2, 3 and 4 (see Table 2) which relate to onsite handling, storage and processing; waste collection; and waste transfer and transport respectively. The limited change in solid waste management approaches was in stark contrast to the numerous institutional changes. Over the 42-year period, there were nine changes, averaging approximately one change every four years, which included variations of centralised municipal management, experimental private sector participation, and interventions/inference by central government.

Table 5: Overview and key features municipal solid waste management approaches adopted by the City of Harare between 1980 and 2023.

Period	Institutional Approach	Responsible institution and main features	Party political control of Harare City Council	Solid waste management approach
1980-1996	Centralised	Department of Works, responsible for all aspects of solid waste management	ZANU PF (same party as central government)	Traditional solid waste management
1996-1998	Centralised, Waste collection partly privatised	- City Health Department 56 % of waste collection zones were outsourced to private waste collectors - City received external financial assistance from donor community and central Government	ZANU PF (same party as one in charge of central government)	
1998-1999	Centralised, Waste collection partly privatised	- City Health Department - Fleet of waste collection vehicles deteriorated from 70 to 19 due to poor maintenance - City outsourced waste collection to private waste collectors	ZANU PF (same party as one in charge of central government). In 1999, Government dismissed the Solomon Tavengwa (a ZANU PF appointee) on alleging maladministration, corruption and incompetence and appointed the Elijah Chanakira Commission to run the City for nearly two years.	
2000-2002	Centralised, Waste collection partly privatised	- City Health Department - Waste collection by both the City and private waste collectors	Movement for Democratic Change (official opposition party)	

2002-2003	Centralised	- Private waste collectors withdraw services because of contracts become unprofitable due to the economic downturn in the country - City Health Department assumes responsibility for waste management	Movement for Democratic Change (official opposition party)	
2004-2010	Centralised	- Creation of Department of Waste (100% owned by the City) with total responsibility for solid waste management as part of the City turnaround plan - All operations centralised by the Department	Movement for Democratic Change (official opposition party)	
2010-2018	Centralised, informal privatisation of waste collection	- City responsible - Return of private waste collectors but informally - Various private organizations assisting City with resources as part of cooperate social responsibility	Movement for Democratic Change (official opposition party)	
2018-2022	Centralised, Experimental privatisation	- City is in control - Pilot project initiated with a private players (Clean City) to assess sustainability of introduction of private waste collectors.	Movement for Democratic Change (official opposition party)	- City drafts an Integrated Solid Waste Management Policy - City starts to operate on solid waste management plans that are reviewed annually
2021-2022	Centralised, informal privatisation, Privatisation of biogenesis aspects	- Department of Waste has overall responsible for waste management but acknowledges existence of private waste collectors - Geoenix BV, engaged by central government in a waste-to-energy project	Movement for Democratic Change (official opposition party)	City tries to resist Geoenix deal but was central government declared it a national project
2023 -	Centralised, informal privatisation, Privatisation of biogenesis aspects	- Department of Waste has overall responsible for waste collection and disposal - Environmental Management Agency instructed by central government to coordinate waste collection on a temporary basis - Geoenix responsible for waste to energy	Citizen Coalition for Change (official opposition party)	Phase I of Pomona Geo... is underway. Geoenix is officially launched by the President

Source: Personnel communication and City records.

The frequent institutional changes were a combination of financial challenges, City's internal re-organization, and governance in the City. As observed below, these mimicked national level politics. The financial challenges in the City started in 1998 when the City, just as happened to other local government authorities in the country, lost donor financial support because of political differences between the central government and donor countries (DCOMM, 2007). This was against a backdrop of withdrawal of central government financial support to local authorities due the Economic Structural Adjustment Programme, which the country adopted in 1990, which required the state to cut public expenditure. All local authorities were to rely on revenue collected from ratepayers for both capital and operational costs. This precipitated a deterioration in the provision of essential services such as solid waste management (Practical Action Southern Africa, 2006). By the year 2000, the City was only collecting 54 per cent of the waste due to shortages of fuel and deterioration of equipment (Tsiko and Togarepi, 2012). Ad hoc intervention by the Central Government to allocate diesel for refuse collection did not address the problem (Koro, 2003).

Waste management in the City has shifted between three departments (Department of Works, City Health Department and Department of Waste). Before 1996, the Department of Works was responsible for waste management, a responsibility that was transferred to the City Health Department after 1996. The Health Department retained responsibility until 2003 when the Division of Waste was established. For the majority of the period, more than one institution was in place. This was the case between 1996 and the present, where centralised approach and some form of privatization, existed side by side. The institutional changes tended to be abrupt or short-term changes and incomplete as was the case in 1996-1998, 1998-1999 and 2002-2003. The changes mainly involved the municipality courting private sector participation. It is, however, important to note that private sector participation was introduced in the City as far back as the mid-1990s, before the administration of opposition-led municipalities. It has continued up to date without a clear strategy. The *Herald* of 13 March 2000 reported that the City cancelled the contract with a private waste collection company because of poor performance. In 2002, the majority of waste collection contracts were not renewed. In 2003, some private players withdrew services because it did not make economic sense. From 2010 privatisation was informal with private sectors allowed to operate but with a formal licence. Privatization only covered waste collection, and was sometimes experimental and informal as was the case between 2010 and 2022. In fact, the City never adopted full privatisation of solid waste management.

City of Harare officials in the Waste Department were sceptical about the advantage of privatization. It resulted in high tariffs for the already financially cash-strapped ratepayers. The best was for the City to provide service at no profit. This, however, has generally failed for various reasons including economic challenges. The governance in the City has also affected and continues to affect solid waste management. While governance has been cast as a clash between opposition-held municipalities and central government (see for example Jonga and Chirisa, 2009), this actually is not correct. Even when the ruling party was in control of the City, the government appointed a Chanakira commission to professionally run the City. The move was precipitated by the water crisis, which also resulted in water being surrendered to the Zimbabwe National Water Authority (ZINWA), a parastatal agency mainly tasked with water resource management and water supply in small urban centres and rural service centres. Water services were returned from ZINWA to the City with no significant improvement.

The City has taken efforts to transition toward sustainable integrated waste management by crafting an Integrated Solid Waste Management Strategic Plan for the City. The City's Integrated Solid Waste Management Strategic Plan, which is meant to guide the transition to sustainable integrated waste management, is not yet operational. Media reports that the City held consultations about the Plan at the end of 2021 (Mpofu, 2021). It is remarkable the Plan is coming nearly two decades after the 2002 World Summit on Sustainable Development held in Johannesburg, South Africa where urgent

attention was recommended toward waste prevention, minimization, and reuse and recycling including developing environmentally sound disposal approaches, such as waste-to-energy technology. It also comes out nearly 10 years after the promulgation of SDG 11, and adoption of Zimbabwe's Integrated Solid Waste Management Plan (GOZ, 2014). The fact that the City's Plan is not yet operational means that the tools that can be used to operationalize sustainable solid waste management do not exist in the City (see Table 3). An exception is the waste to energy, which however, is not part of the City as described below.

The lack of a clear plan for solid waste management by the City has provided opportunities for central government to intervene in the City (which is also true in other urban areas) since 2000 when opposition parties took control of many urban municipalities. Central government has alleged incompetence and corruption. Municipalities have alleged the same. The most significant 'interference' from a financial perspective, was the 30-year contract, valued at US\$316 million, that awarded by central government to Geogenix BV, a Netherlands-based company in 2021 (Ndlela, 2023). Under this contract, the City of Harare would pay Geogenix BV US\$22,000 per day to dispose waste at the Pomona dumpsite. As noted above, Pomona owned by the City. Geogenix, would design, build, operate and transfer a waste-to-energy project at Pomona dumpsite that would generate up to 22MW of electricity under a Build, Own, Operate, and Transfer (BOOT) joint venture agreement. The Harare Council initially refused to be part of the arrangement, arguing that the City was not consulted, that the deal was not in the interest of the City, and that the City did not have the kind of money. The central government insisted that this was a national project. The City eventually relented (see section 4.2.3).

4.2 Current solid waste management practices

4.2.1 City of Harare

Operationally, the City's Waste Department has divided the City into 80 waste collection zones based on the location, size, amount of waste generated. Residential areas with high population are divided into sub-zones. For example, Budirio is divided into subzone 'A' and B 'B'. During the time of the study, all the zones were serviced by a fleet of 28 waste collection vehicles, which was 40% of the number of trucks required by the City (Department of Waste, personal communication). Consequently, waste in some areas remains uncollected for months resulting in illegal waste dumping in residential and at shopping centres. In March 2022, the Environmental Management Agency established that there were over 7000 illegal waste dumps in the City. The mapping exercise was coordinated by the Agency in their efforts to monitor waste management. The agency filed a court application compelling the City council to mobilise waste collection (The Herald, 10 April 2022). Nothing significant came out of the fines that were imposed.

There is a waste collection schedule for all the zones. Table 6 shows an extract of the waste collection schedule for different zones and the Trucks that are dispatched to collect waste on scheduled days. Waste collection is scheduled to be done at least once a week in residential areas while in commercial areas it is at three times a week. The City used to provide waste bins for residential areas until early 2016 but this was suspended because of financial constraints. Residents use their own disposable bin liners or empty sacks as waste receptacles. The City provides skip bins at business centres, which are supposed to be emptied at least three times per week or as and when the resources permit ;such as the one at Warren Shopping Centre (Figure 3).

Table 6: Extract of Refuse Collection Schedule in residential areas in the City of Harare

Main collection zone	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
	Specific collection area					
Belvedere	Belvedere North Area bounded by S.Machel Avenue, Prince Edward Street, Princess, Comerty & Beal Road	Area bounded by Samora Machel Avenue & Beal Road	Milton Park	Ridgeview and Lincoln Green area bounded by Garfield Road	Monavale	No collection
Borrowdale 'A'	Area bounded by Harare Drive, Gaydon Road, Warwick Road, Winchcombe Road .& Newbold Road	Area bounded by Campbell Avenue and Harare Drive	Area bounded by Borrowdale Road	Area bounded by Arnold-Edmonds Drive & Enterprise Road	Area bounded Crowhill Road ., Carrick Creagh, Hessel Road & Gaydon Road	Area bounded by Shawasha Hills, Umwinsdale
Mt Pleasant	Area bounded by University of Zimbabwe Pendennis & Bargate	Area bounded by 2 nd Street Extension, Upper East & Norfolk	Area bounded by Norfolk, 2nd Street Extension	Vainona- Area bounded by Bargate & Harare drive	Manzil and Mt-Pleasant Heights	No collection
Warren Park	No collection	No collection	Westlea -Area bounded by The Vlei, Bulawayo Road and Tynwald Road	No collection	No collection	No collection
Industrial Areas	Msasa	Workington	Southerton and old Adberni	Granite side	Willowvale	No collection
Budiriro A			Round about- Budiriro 1-3			
Budiriro B					Budiriro 4-5 and Current shops	

Source: Extract of City of Harare refuse collection schedule



Figure 3: Skip bin at Warren Park shopping centre

Residents generally regard waste collection by the City to be inadequate. Across all the residential areas, waste collection was rated to be inadequate (Figure 4).

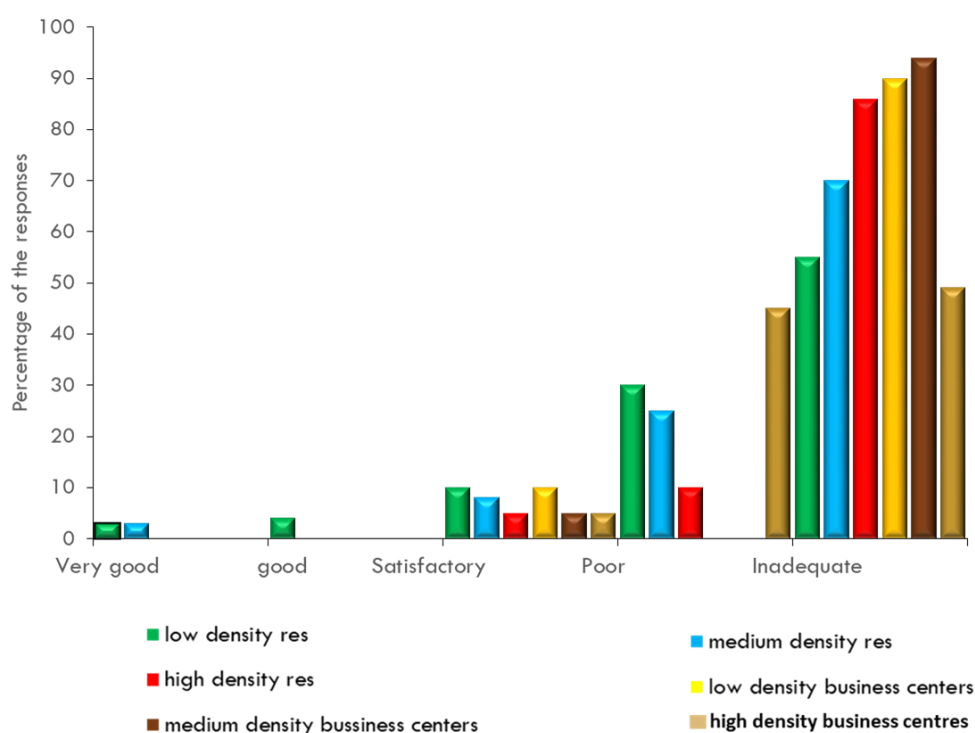


Figure 4: Perception of effectiveness of waste collection across selected high, medium and low-density areas in the City of Harare

Infrequent waste collection was cited as the main reason for inadequacies in waste collection (Figure 5). Less than 45% of respondents reported that waste was collected as the scheduled once a week. The figures of waste being collected once a month were also relatively high. The fact that there were reports of waste being after six months and more indicates the poor status of waste collection in the

City. In general, waste collection was better in the affluent (low and medium density areas) suburbs although the frequency was below standard.

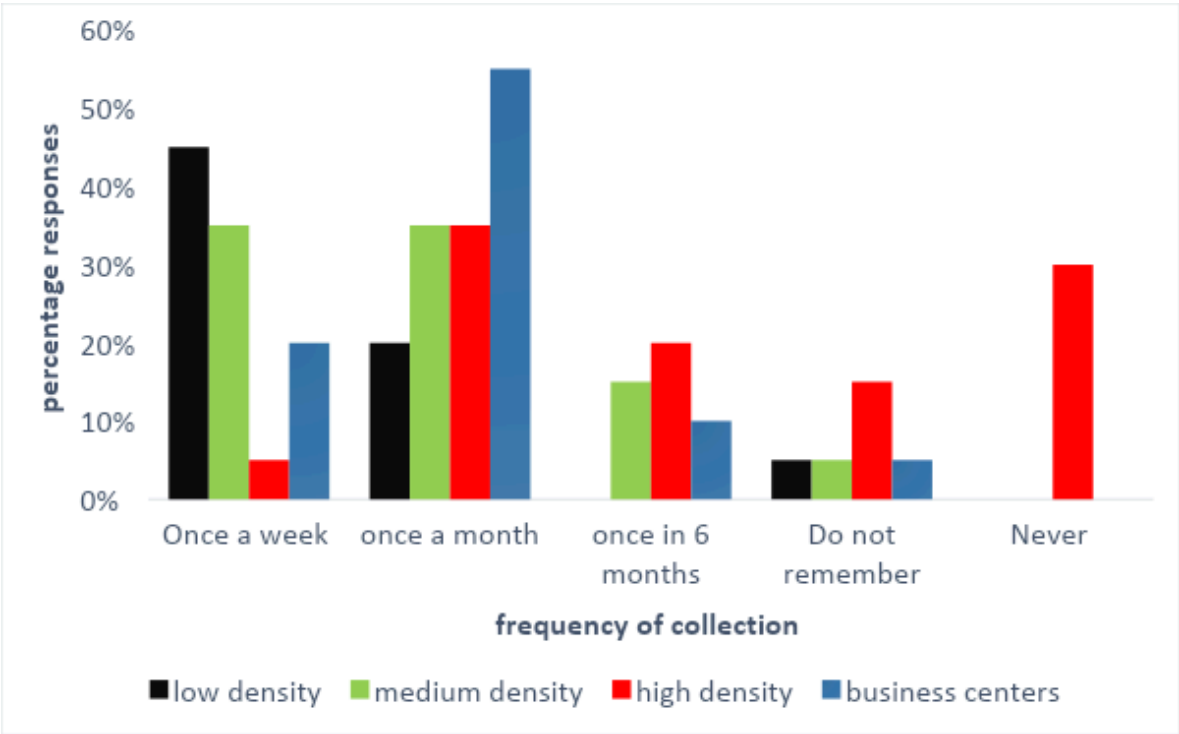


Figure 5: Frequency of waste collection across selected residential areas and business centres in the City of Harare

Poor waste collection resulted in residents resorting to illegal and unsafe ways of managing waste such as burning and illegal dumping, and to private players (Figure 6).

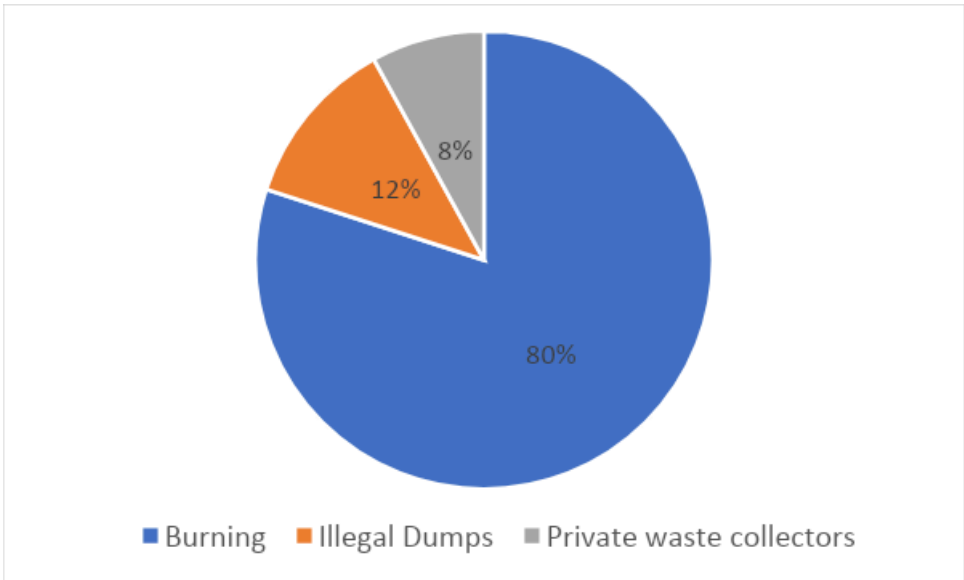


Figure 6: Alternative disposal methods suggested by residents in the City of Harare

4.2.2 Private Service providers

This section presents an overview of solid waste collection by three private service providers, which were given by the City to operate in designated areas. These include Clean City Africa, Madhodha Bin and The Republic Waste.

Clean City Africa

In 2019, the City of Harare launched a pilot project with Clean City Africa, a privately owned organization that provides cleaning, sanitation, and services including waste collection, to learn lessons for introducing private service providers in the City. Under the agreement, Clean City Africa would collect waste from 40 designated waste collection zones between 2020 and 2021 (Figure 7). The company would use its own fleet of waste collection vehicles and would receive a subsidy of 50% from the City. The company would not collect fees from ratepayers but would receive payment from the City of Harare.



REFUSE COLLECTION TIME-TABLE

COLLECTION DAYS (SPECIFIC AREAS)

MAIN AREA	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY	SUNDAY
ALEX PARK	Gunhill	Borrowdale West and Dandaro			Old and New Alex Park		
AVENUES	Area bounded by J.Tongogara, L.Takawira, H. Chitepo, Sam Nujoma	Area bounded by J.Tongogara, 4 th St, S. Machel and S.Nujoma	Area bounded by J. Tongogara, Prince Edward, H. Chitepo and L.Takawira St	Area bounded by J.Tongogara, 4 th st, S.Machel and 7 th st	i. Area bounded by S.Machel, 4 th st, R.Mugabe, & Enterprise rd ii. Area bounded by Cork rd, L.Takawira & S.Nujoma Incl Parirenyatwa	Area bounded by J.Tongogara, Enterprise rd, 7 th st & S.Machel	Daily's le Hotels, Restaurants, Hospitals & all Shops
AVONDALE	Area bounded by Cork rd 2 nd st, Aberdeen rd & King George	Area bounded by Cork rd, King George, West rd & Lomagundi rd	Area bounded by Lomagundi rd, West rd, Kerry rd & Suffolk rd	Strathaven	Area bounded by King George, Aberdeen rd, 2 nd street Ext and Lomagundi		
BELVEDERE	Belvedere North Area bounded by S.Machel, Prince Edward Str, Princess, Comerty & Beal Rd.	1. Area bounded by Samora Machel, Beal Rd, Princess and Mutley Bend. 2. Lincoln Green area bounded by Garfield rd up to Watermeyer rd	Milton Park	Ridgeview and Lincoln Green area bounded by Garfield rd and Bishop Gaul Rd.	Monavale		
BUDIRIRO 'A'	Budiriro 1 Southern Side. Area bounded by Second rd, Third rd, Willowvale rd up to Budiriro Park	Budiriro 1 Southern Side Area bounded by Second rd and Third rd	Budiriro 1 North (Clinic area) up to Nzou st	Budiriro 2	Budiriro 5B up to OK Shops – Southern Side		
BUDIRIRO 'B'	Budiriro 5B- Northern Side up to Current Shops	Budiriro 5A & Budiriro 4 area to the East of Budiriro 4 main rd	Budiriro 4 area to the west of Budiriro 4 main rd & Budiriro 4 Ext	Budiriro 3 – area to the North of 87 th drive	Budiriro 3 – area to the South of 87 th drive bounded by 17 th ave, Willowvale rd and 2 nd rd	Budiriro 5- Current consortium	
BORROWDALE 'A'	Area bounded by Harare dr, Gayden Rd, Wanwick rd, Winchcombe rd and Newbold rd	Area bounded by Campbell Ave, Harare dr, Port-Glen rd and Piers rd	Area bounded by Borrowdale rd, Piers rd, Harare dr, Addington Lane and Rolf ave	Area bounded by Arnold-Edmonds dr, Enterprise rd, Manyonga East –Hills, Lytham dr and Elshadai rd	Area bounded Crowhill rd, Carrick Creagh, Hessel rd and Gaydon rd	Area bounded by Shawasha Hills, Umwinsdale, Mujuru Homestead and Hogerty (new stands)	

Source: www.cleancityafrica.com)

Figure 7: Extract of schedule for waste collection of Clean City Africa

According to the schedule of the pilot project, Clean City covered more zones and frequently than the City of Harare. While there was some improvement in waste collection, the pilot project did not yield favourable terms to both the City and Clean City and was discontinued. Clean City has continued to operate as a private entity offering its waste collection services at a fee. By 2022, during the time of the research the contract between Clean City and the City was yet to be concluded. Considerations were still being made to ensure the sustainability of the business.

Madhodha Bin

Madhodha Bin is a private waste collection service provider, which operates in low income high-density areas such as Budiro, Glenview and Mufakose. It operates without any written agreement with the City. It pays waste disposal fees of USD40 per tonne to the City for every truckload of waste disposed at Pomona dumpsite. The company offers waste collection services on the basis of a number of conditions. First, residents should be in groups, and each group should be made up of at least 30 households. Second, residents are required to lodge a request for the service through local ward_ councillor. Third, each household is required to make a monthly payment of USD10. Waste is collected on a seven-day cycle. The company also offers a same day waste removal service, which is charged per tonne and the distance from source to waste disposal site. Each household is provided with plastic bin liners and is expected to generate a maximum of two waste bags per week. Extra waste attracts a charge of US\$1 per bag. Out of the 900 households in a waste collection zone that sBudiro 5B Cabs area, the Company provided service to up to 134 households up from an initial of 40.

Residents have found a way of optimising waste collection. One respondent explained it like this:

When my household started subscribing to the waste collection service, we would generate more than two bags of waste because waste had accumulated in the household for some time due to non-collection by the City of Harare. After consistent collection by Madhodha Bin, we can hardly fill two bags. Therefore, my neighbour and I are now sharing the monthly payment. We generate one bag per household and our waste is collected at one point as waste generated by one household. This is how we are coping with the expense of waste collection and managing to keep our community clean (Field notes, 17 April 2022).

The majority of respondents in Budiro are satisfied with the service (Figure 8). As can be seen, well over 80% of the respondents' rate service as good.

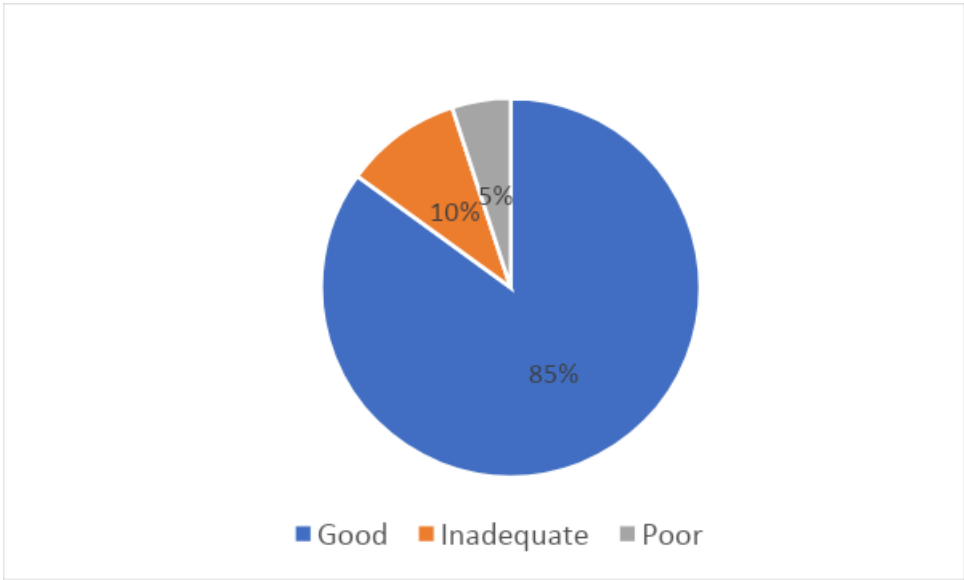


Figure 8: Budiro residents' rating of quality of waste collection service provided by Madhodha Bin

The Republic Waste

The Republic Waste is a private entity, which mainly operates in low-density areas and in gated communities where organizing waste collection is easier than the high density areas. The Company mainly offers services for corporations and institutions. The charge is reduced if waste is collected from

one central point. The cost of collecting four bags of waste per month per household is reduced from US\$15 to US\$10 where there are at least five households in the same street for a more coordinated waste collection system. Extra bags of waste attract a charge of US\$1. Republic waste also offers a once off collection charge depending on the quantity of waste and is charged per distance.

Residents receiving service from The Republic Waste rated the service as satisfactory. Satisfaction with service was attributed to consistency of service. Some households in these areas are not willing to pay for private waste collection stating the reason that waste collection is the mandate of City Council which they pay for as fixed rates. Consequently, illegal waste dumps were observed in these residential areas despite the collection by private waste collectors.

4.2.3 Beyond mid-2022

Solid waste management continued to be a problem beyond the study period (mid-2022). This necessitated the central government to take action. On 31 July 2023, the Government of Zimbabwe promulgated Statutory Instrument 140 of 2023, which declared a state of disaster in the Harare Metropolitan province (in which the City of Harare is located) because of “the deplorable state of [un]cleanliness and characterised among other things by litter and waste dumps accumulating in business and residential areas, open burning of garbage and indiscriminate illegal dumping of solid waste and littering” (Government of Zimbabwe, 2023). The statutory instrument mandated the Environmental Management Agency, the parastatal organisation mandated to manage the environment in the country (Government of Zimbabwe, 2002), to intervene as follows. The Agency would co-ordinate use of materials and services available by local authorities, remove illegal solid waste dumps, direct local authorities to establish appropriately designed and designated waste transfer stations, undertake periodic refuse collection, install bins, and undertake awareness campaigns. If necessary, the Agency was mandated to legally recover expenses incurred during the discharge of the mandated duties. The Agency started collecting waste but not for long because of other developments (see below). It is important to state this was a financial burden to the Agency. It campaigned for a waste collection fee. This did not materialize.

In response to the cholera outbreak, which started in February 2024 and peaked in the last quarter of 2024, the Government launched a clean-up campaign in Harare called “Operation Chenesa Harare”. The campaign was designed to restore proper hygiene standards and cleanliness in the central business district and residential areas. The week-long campaign mobilized 36 trucks to clear solid waste dumps. The City was divided into different regions to facilitate efficient waste removal, with specific areas targeted for the clean-up. However, the waste dumps re-surfaced leading people to question the sustainability of the programme.

The clean-up campaign benefitted Geogenix BV, which now operated as Geo Pomona Waste Management Pvt Ltd. After the first week of Operation Chenesa Harare, Geo Pomona Waste Management Company took delivery of 4 000 tonnes of waste. While the amount of waste delivered before the operation is not started, the Company was grateful for the increased solid waste that was delivered. This showed that the waste-to-energy project was a stand-alone project, separate from waste collection in the City. The project would suffer from inadequate amounts of feedstock if the City did not collect enough waste. The City of Harare had no incentive to collect and deliver waste because this would translate in incurring huge costs.

Meanwhile Geo Pomona Waste Management has continued to implement the project. The President of the Republic of Zimbabwe, Emmerson Mnangagwa, officiated at the ground-breaking ceremony in December 2023 during which the Company reported significant progress. This included completion of Phase 1, which included preparatory work for construction of the waste to energy plant, and

construction of social amenities such as recreational areas, restaurants as well as basketball and tennis courts. There were also plans to construct landfills for waste.

At the ceremony, the Company reported good working relations with Harare City Council. This was not reciprocated by the Mayor, who diplomatically reiterated that the City still had some reservations about the project, and implored central government to address the issues. He did not have the opportunity to pursue the matter. The Interim Secretary General of the Citizens Coalition for Change political party replaced him a few weeks later as part of recall campaign of parliamentarians and local councillors.

V. CONCLUSIONS

Municipal solid waste management in Harare has deteriorated since independence in 1980, and has caused and is causing serious environmental and health challenges. What is peculiar about the deterioration is that this has happened against a backdrop of frequent institutional changes. There were nine institutional changes (one in every four years), involving variations of centralised management by the City, limited and experimental private sector participation, and interventions by central government. The changes were a combination of changes in the City's internal re-organisation, financial challenges precipitated by an economic downturn in the country at large, and dynamics in the urban political landscape, itself a mirror of national level party politics. The economic downturn, among others, resulted in the City failing to provide the requisite social services, and inviting private sector participation as early as the 1990s, ten years after independence. Private sector participation, which was wholly local (Zimbabwean), was restricted to waste collection. The arrangement collapsed because the private sector could not make money. Other efforts at private sector participation ended the same way with the result private sector participation is now experimental. Re-organisation in the City, such as moving solid waste from one department to another and creation of stand-alone division, did not produce any changes. The intervention by central government, even when the ruling party was in control of the City during the first decade of independence, had no positive effect. The urban political landscape was complex after 2000 when the opposition party gained control of the City and is said to have attracted more central government interference. While the interference by central government has been blamed for deterioration, this is entirely not correct. The opposition party itself has been riven by squabbles. The City has also failed to implement more environmental friendly practices. As observed, the City's Sustainable Waste Management Plan is being put in motion nearly two decades after the 2002 World Summit on Sustainable Development, which emphasized waste prevention, minimization and recycling (including promotion of waste to energy technologies), almost a decade after promulgation of SDG 11 and adoption of Zimbabwe's Integrated Solid Waste Management Plan.

The institutional changes were in many ways cosmetic because solid waste management in the City continued to be dominated by traditional approaches, particularly waste collection. It did not incorporate aspects of sustainable integrated waste management such as decentralization, incorporation of the informal sector or circular economy principles. The fact that the City has just a draft Integrated Solid Waste Management Strategic Plan, which was reported to be under discussion in 2023, shows that the City has no clear strategy for managing solid waste management in the City, and has provided an opportunity for central government to interfere, as indicated by the Geo Pomona Waste Management project. Unfortunately, the project is not integrated in the City of Harare's plans. The City of Harare has no incentive to collect waste and transport it to Pomona, as this attracts a large daily payment. This may hamper if not jeopardize the operations of the company. The current institutional fragmentation—a situation where multiple public, private, and quasi-government agencies operate within the same policy domain (Elsässer et al., 2022) confirms that waste management is a

complex problem characterised by multi-layered interdependencies and complex social dynamics (Ghiani et al., 2014; Salvia et al., 2021; Soltani et al., 2017).

The City of Harare needs to rapidly adopt and implement sustainable integrated solid waste management approaches. In this regard, the focus should not be just on traditional waste collection and transporting to central dumpsites. There is a need to transition towards sustainable integrated waste management. An important component for a city in developing country like Zimbabwe is inclusion of household or local level approaches such as decentralization and incorporation of informal solid waste collectors, which has been successfully implemented in other cities in the developing world. This will not only contribute to a clean city but to improved livelihoods of many residents where poverty levels are high. Such an approach can improve solid waste management, not only in Harare but also in other cities in Zimbabwe and in sub-Saharan Africa. Municipal solid waste governance is also an important component towards the transition.

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Current Situation of Plastic and its Recycling as Material for Rural Construction

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ABSTRACT

The circular and climate-neutral plastics economy uses and manages plastics in a sustainable way. These days, there is an excessive accumulation of plastic waste and its recycling has become paramount. Polyethylene terephthalate (PET) and polypropylene (PP) are among the most consumed and wasteful plastics. One solution to repel these wastes is to recycle them into construction materials. The objective of this work was to develop a hybrid material between recycled PET and PP plastics and aggregate material to be used as paving stones in rural construction floors. The best combinations were obtained for pavers, presenting compression values between 20 and 25 Mpa and flexural-traction values of ± 10 Mpa, which are comparable to concrete or concrete blocks and pavers, but with a much lower weight. The percentage of water and humidity absorption obtained was $\leq 1\%$, which is within the permissible limits under the ECUATORIAN STANDARD INEN 3040 for concrete pavers and the EUROPEAN STANDARD UNE EN 1338 for cement and concrete prefabricated products. Obtaining light, resistant and low cost materials that can serve as an option to conventional construction materials.

Keywords: recycling, rural constructions, eco-paving stones, polyethylene terephthalate (PET), high-density polyethylene (HDPE), polypropylene (PP).

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Current Situation of Plastic and its Recycling as Material for Rural Construction

Situación actual del plástico y su reciclaje como material para la construcción rural

Dr. María Jos Valarezo-Ulloa

RESUMEN

La economía circular y climáticamente neutra de los plásticos utiliza y gestiona este tipo de materiales de forma sostenible. En estos días, existe una excesiva acumulación de desechos plásticos y su reciclaje se ha vuelto primordial. El tereftalato de polietileno (PET) y polipropileno (PP) son unos de los plásticos que más se consumen y más desechos generan. Una solución para repeler estos desechos es reciclarlos en materiales para la construcción. En el presente trabajo tuvo como objetivo el desarrollo de un material híbrido entre plástico reciclado tipo PET y PP; y material árido para utilizarse como adoquín en pisos de construcciones rurales. Se obtuvieron las mejores combinaciones para adoquines, presentando valores de compresión entre 20 y 25 Mpa y de flexo-tracción de ± 10 Mpa que son equiparables a adoquines y bloques de hormigón o concreto, pero con un peso mucho menor. El porcentaje de absorción de agua y humedad, obtenido fue de $\leq 1\%$, el cual se encuentra dentro de los límites permisibles bajo la NORMA ECUATORIANA INEN 3040 para adoquines de hormigón y la NORMA EUROPEA UNE EN 1338 para prefabricados de cemento y hormigón. Obteniendo materiales livianos, resistentes y a bajo costo que pueden servir como una opción a los materiales convencionales de construcción.

Palabras clave: reciclaje, construcciones rurales, eco-adoquines, polietileno tereftalato (pet), polietileno de alta densidad (pead), polipropileno (pp).

ABSTRACT

The circular and climate-neutral plastics economy uses and manages plastics in a sustainable way. These days, there is an excessive accumulation of plastic waste and its recycling has become paramount. Polyethylene terephthalate (PET) and polypropylene (PP) are among the most consumed and wasteful plastics. One solution to repel these wastes is to recycle them into construction materials. The objective of this work was to develop a hybrid material between recycled PET and PP plastics and aggregate material to be used as paving stones in rural construction floors. The best combinations were obtained for pavers, presenting compression values between 20 and 25 Mpa and flexural-traction values of ± 10 Mpa, which are comparable to concrete or concrete blocks and pavers, but with a much lower weight. The percentage of water and humidity absorption obtained was $\leq 1\%$, which is within the permissible limits under the ECUATORIAN STANDARD INEN 3040 for concrete pavers and the EUROPEAN STANDARD UNE EN 1338 for cement and concrete prefabricated products. Obtaining light, resistant and low cost materials that can serve as an option to conventional construction materials.

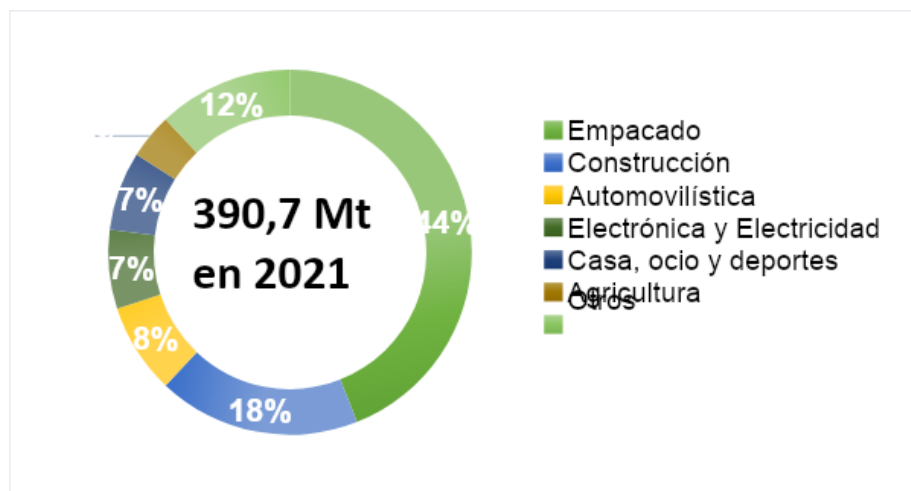
Keywords: recycling, rural constructions, eco-paving stones, polyethylene terephthalate (PET), high-density polyethylene (HDPE), polypropylene (PP).

I. INTRODUCCIÓN

Los plásticos son materiales que han acompañado al ser humano desde hace mucho tiempo atrás y su producción ha aumentado a medida que la demanda de este material ha ido creciendo. Este hecho se ha evidenciado en diferentes áreas en las que el plástico ha sido requerido, como la industria alimentaria, automotriz, de la construcción, utensilios médicos; y de uso diaria entre otros. Solo en el año 2021, la producción mundial de plásticos aumentó un 4% más que el año anterior, hasta superar los 390.7 millones de toneladas, tras un estancamiento en 2020 debido a la pandemia de Covid-19 lo que demuestra la fuerte y continua demanda de este material (Plastics Europe, 2022).

A nivel mundial China es el país que mayor cantidad de plástico genera, representando el 32% de la producción, seguido de Estados Unidos, el resto de Asia y la Unión Europea. Latino América produce tan solo un 4%. De estas cifras se puede citar que el 90.2 % es plástico de origen fósil, 8.3% es de plástico reciclado y un 1.5% corresponde a bioplásticos (Plastics Europe, 2022).

A pesar de la creciente preocupación de activistas ambientales en relación con la contaminación mundial por plástico, se prevé que la demanda de este tipo de materiales siga aumentando. En 2021, el sector del envasado tubo la mayor cuota con un 44%, seguido de la edificación y la construcción (18%), la automoción (8%), la electricidad y la electrónica (7%), el hogar, el ocio y el deporte (7%), agricultura, ganadería y jardinería (4%), y otros (12%), como se muestra en la Figura 1. Esto se atribuye un estilo de vida moderno, a el consumismo y al hecho de que aún no estamos totalmente consciente del problema que está generando la acumulación indiscriminada de plástico en todo el mundo (Jouyandeh et al, 2023) (Tiseo, 2021).



Nota. Demanda mundial de plástico, datos obtenidos de Plastics Europe, 2022

Figura 1: Demanda mundial de plástico

Sin embargo, no todo es negativo en el mundo de los plásticos, existen iniciativas de manejo de residuos que necesitan apoyo por parte de diferentes entidades públicas y privadas, ya que las tasas de reciclaje a nivel mundial aún son bajas. La falta de tecnología, la mala gestión de recursos, la falta de programas coherentes y procesamiento incompleto de estos plásticos han hecho que este problema se acentúe (Darko et al, 2023) (Jung et al, 2023).

Debido a esto el reciclaje de plásticos representa una opción implacable para lograr una producción cero residuos y climáticamente neutra que exija una inversión e innovación por parte de la cadena de valor de los plásticos para desarrollar nuevos modelos de negocio para su reutilización. Logrando así emplear una mayor cantidad de plástico reciclado para el desarrollo de nuevas tecnologías que

dependan menos de materiales de origen fósil y contribuyan a la reducción de la acumulación de desechos plástico en botaderos, rellenos sanitarios, bosques, ríos, etc.

Dado que el reciclaje mecánico de plásticos requiere menos capital y recursos, podría ser una opción de gestión de residuos adecuada, en especial en países en desarrollo como Ecuador. Una estrategia importante para consumir este material de desecho es su reciclaje en proyectos de construcción rural, al poseer una buena resistencia mecánica, barrera eficaz contra los gases, resisten a la corrosión, ser ligeros, fáciles de instalar, termosellables y están disponibles a bajo costo, lo que los hace ideales para la fabricación de diversos productos en esta área. (Naveena & Sharma, 2020), (Jouyandeh et al, 2023).

En la construcción, los plásticos abundan en cañerías, revestimientos, pisos, aislamiento, paneles, puertas, ventanas, cristales, unidades de baño, rejas, barandillas y una lista cada vez mayor de aplicaciones tanto estructurales como interiores o decorativas. Sin embargo, las construcciones rurales a diferencia de las urbanas deben cumplir condiciones muy específicas que están determinadas por su entorno, factores socio culturales y rubros que se exploten. Es así, que las viviendas que ocupan las familias forman un conjunto indisoluble con las instalaciones agrícolas y pecuarias.

Brindando así, una amplia gama de oportunidades para nuevas instalaciones relacionadas a la explotación de la tierra, la crianza de animales domésticos, terrazas, embalses, corrales, sistemas de riego, depósitos para guardar alimentos, silos para conservar granos, áreas en donde el uso de recursos inocuos como materiales elaborados a base de plástico reciclado podrían tener cabida.

Con la presente investigación se pretende suplir una necesidad para pisos en construcciones rurales brindando un material inocuo, ligero, de bajo costo, resistente a la humedad, con propiedades físico mecánicas óptimas para ser utilizados en una versatilidad de áreas tanto para vivienda como otras instalaciones de explotación pecuaria y agrícola. Se empleó dos tipos de residuos plásticos: polipropileno (PP) y polietileno tereftalato (PET) mezclado con materiales áridos para la elaboración de eco-adoquines.

El proyecto se realizó dentro del convenio macro entre el Centro Integral de Manejo de Residuos Sólidos del Municipio de Loja-Ecuador y la Universidad Nacional de Loja-Ecuador para tratar de generar conciencia en la factibilidad de uso de materiales de desecho para la elaboración de nuevos materiales, contribuyendo a la disminución de contaminación por plástico, a la utilización de recursos naturales y promoviendo la economía circular.

II. MATERIALES

La ciudad de Loja-Ecuador cuenta con un sistema de recolección y clasificación de basura realizada por el Municipio de Loja por lo que las botellas y envases de polipropileno (PP) y polietileno tereftalato (PET) se obtuvieron del Centro Integral de Manejo de Residuos Sólidos administrado por dicha entidad gubernamental. Los áridos finos y gruesos se obtuvieron de la Cantera Yamba, parroquia Malacatos, cantón Loja-Ecuador. El Alcohol etílico C_2H_6O (70%) se compró en Sigma-Aldrich para limpieza de los plásticos.

III. MÉTODOS

3.1 Obtención y preparación de las materias primas

Las botellas y envases de plásticos de tereftalato de polietileno (PET) y polipropileno (PP) se recogieron del Centro de Manejo Integral de Residuos Sólidos del Municipio de Loja-Ecuador. Como se muestra en la Figura 2.



Figura 2: Centro de Manejo Integral de Residuos Sólidos del Municipio de Loja

Una vez recolectados fueron llevados al Centro de Investigación y Servicio de Análisis Químico CISAQ de la Universidad Nacional de Loja, donde se clasificaron, lavaron y secaron. El lavado de los desechos plásticos se realizó con agua destilada, jabón y alcohol etílico al 70% con tres repeticiones para evitar que cualquier impureza quede adherida a la superficie del material. Luego los desechos plásticos se esparcieron sobre una superficie plana y se secaron a temperatura ambiente $\pm 21^{\circ}\text{C}$ durante 48 horas.

3.2 Proceso de trituración de los residuos plásticos

Para el proceso de trituración del material plástico se utilizó un triturador de aspas que está conformado por una tolva o boca de entrada, un motor, un rotor de aspas y un tamiz o criba. El tamiz es colocado para permitir el paso de los trozos más pequeños de plástico resultados del proceso de trituración. Los tamaños de la criba se muestran en la Tabla 2. El triturador de plásticos se muestra en la Figura 3.

Tabla 2: Tamaño de partícula de plástico

Tamaño diámetro de criba	Dimensiones (mm)
Grande	0.5
Mediano	0.25
Pequeño	0.1



Figura 3: Triturador de aspas de plásticos

Una vez que el material fue triturado, se sometió a un proceso de secado en estufa durante 24 horas o hasta alcanzar un porcentaje de humedad $\leq 1\%$.

3.3 Elaboración de los eco-adoquines

Para la elaboración de los eco adoquines se utilizó un proceso de extrusión, que permite modelar y fundir el plástico a flujo constante de presión y fuerza. Para el proceso se utilizó un extrusor de tornillo sin fin, que consta de una tolva para el ingreso del material, un motor, un rotor, un cilindro o cañón, un tornillo sin fin de 100 cm de largo, un cabezal y una boquilla de diámetro variado; como se muestra en la Figura 3. El proceso de calentamiento se realizó a través de dos resistencias eléctricas ubicadas al exterior del cañón, conocidos también como calefactores. Se estableció un rango de temperaturas de trabajo entre 160°C a 260°C tomado en cuenta la temperatura de fusión de ambos polímeros.



Figura 3: Extrusor de plásticos

Primero, se realizaron pruebas preliminares de mezclas entre el plástico reciclado tipo PET, polímero muy frágil y quebradizo y el polipropileno PP, material con una mayor flexibilidad luego del recalentamiento. Las mezclas se realizaron en las siguientes proporciones como se muestra en la Tabla 3.

Tabla 3: Proporción de mezcla de plásticos PET y PP para elaboración de eco-adoquines

	PET	PP
% Mezcla de plástico reciclado	100	0
	75	25
	50	50
	25	75
	0	100

Cada una de las mezclas se realizaron por duplicado y se evaluaron en función de su porcentaje de absorción de agua, humedad, densidad, resistencia a la compresión y resistencia a la flexo-tracción. A partir de los resultados obtenidos se seleccionó la proporción 50:50%_{PET/PP} y se combinó con diferentes tamaños del material árido en tres proporciones: 75:25%_{PLÁSTICO: ÁRIDO}, 50:50%_{PLÁSTICO: ÁRIDO} y 25:75%_{PLÁSTICO: ÁRIDO}. Para cada tratamiento se realizaron dos repeticiones de cada una y se analizaron las cinco variables anteriormente mencionadas.

La recolección de los áridos finos y gruesos se realizaron en la cantera Yamba del Barrio Malacatos, Cantón Loja-Ecuador. Las muestras para la realización del proyecto se tamizaron y lavaron, para evitar

la presencia de impurezas en las misma. Adicional a este tratamiento los áridos se sometieron a un proceso de secado en estufa durante 24 horas o hasta alcanzar un porcentaje de humedad $\leq 1\%$. Se trabajó con cuatro tamaños diferentes de partícula como se muestra en la Tabla 4.

Tabla 4: Tamaño de partícula de los áridos

Áridos	Tamaño de partícula
(Finos y Gruesos)	Grande (± 10 mm)
	Mediano (± 5 mm)
	Pequeño (± 3 mm)
	Muy pequeño (± 1 mm)

Una vez obtenidas las mezclas fundidas en las distintas proporciones se colocaron en moldes y se prensaron, garantizando la ausencia de burbujas. Las piezas se dejaron enfriar a temperatura ambiente y posteriormente se sumergieron en agua fría $\pm 21^{\circ}\text{C}$.

Los moldes se elaboraron a partir de acero inoxidable y tuvieron las dimensiones recomendadas por la NORMA NTE-INEN para la elaboración de probetas para análisis físico-químicos de bloques y adoquines.

3.4 Variables de estudio

3.4.1 Resistencia a la compresión (C)

La resistencia a la compresión es el esfuerzo máximo que puede soportar un material bajo una carga de aplastamiento, la cual se calcula dividiendo la carga máxima por el área transversal original de una probeta en un ensayo de compresión. En la presente investigación se realizó el ensayo de la resistencia a la compresión bajo la norma española UNE 41410.

3.4.2 Índice de absorción total de agua (AA)

El porcentaje de absorción de agua se midió a través de la NORMA NTE INEN 3040. Este método consiste en la impregnación con agua de la probeta (M_i), y luego la suspensión de la misma en un recipiente con agua durante 24 horas. Se seca el agua superficial de la probeta y se toma su peso (M_s), posterior a esto, se coloca la probeta en la estufa a 100°C durante 24 horas y se vuelve a realizar la lectura del peso (M_d).

El índice de absorción de agua se expresa relacionando la diferencia del peso de la probeta saturada menos el peso de la probeta seca contra el peso de la probeta seca, expresado en porcentaje. Para calcular la absorción de agua se utiliza la siguiente formula.

$$AB (\%) = \frac{M_s - M_d}{M_s - M_i} \times 100$$

En dónde;

- M_s es la masa de la unidad saturada (kg),
- M_i es la masa de la unidad sumergida (kg),
- M_d es la masa de la unidad seca al horno (kg).

3.4.3 Resistencia a la flexión y carga de rotura a temperatura ambiente ($\pm 21^{\circ}\text{C}$), frío ($\pm 10^{\circ}\text{C}$) y calor ($\pm 30^{\circ}\text{C}$). (RF)

El ensayo de tracción por flexión consiste en la aplicación de una fuerza vertical (P) a una velocidad definida al centro de la muestra colocada horizontalmente sobre dos soportes (L) hasta llegar a la rotura de la misma (F). La fórmula para obtener el valor de la resistencia al flexo tracción es la siguiente:

$$f = \frac{3PL}{2bh^2}$$

Donde:

F= resistencia flexo Tracción (Mpa)

P= Carga de rotura (N)

L= luz entre soportes (mm)

b= ancho de la baldosa (mm)

h= espesor de la baldosa (mm)

3.4.4 Contenido de humedad (H)

Para calcular el contenido de humedad de la unidad entera al momento en que se determina la masa recibida (cuando se mide M_r) se utiliza la siguiente formula.

$$H (\%) = \frac{M_r - M_d}{M_s - M_d} \times 100$$

En dónde;

M_r es la masa de la unidad tal como se recibe (kg),

M_s es la masa de la unidad saturada (kg),

M_d es la masa de la unidad seca al horno (kg).

El cálculo anterior del contenido de humedad solo es aplicable a la unidad entera al momento en que se determina la masa tal como se recibe, M_r .

3.4.5 Densidad (ρ)

Para calcular la densidad de la unidad seca al horno se utiliza la siguiente formula:

$$D (kg/m^3) = \frac{M_d}{M_s - M_i} \times 1000$$

En dónde;

M_d es la masa de la unidad seca al horno (kg).

M_s es la masa de la unidad saturada (kg),

M_i es la masa de la unidad sumergida (kg)

IV. RESULTADOS Y DISCUSIÓN

4.1 Tamaño de partícula del plástico

Para la elaboración de los eco-adoquines, se seleccionó el tamaño de diámetro de partícula de plástico de 0,25 mm. La selección de este tamaño se debió al ser el óptimo para trabajar dentro del rango de temperaturas durante el proceso de fusión del PET (260°C) y PP (160°C) para la formación de los eco

adoquines, evitando que descomposición de los plásticos durante el calentamiento y garantizando la conservación de sus propiedades físico-mecánicas y termo-elásticas.



Figura 4: Residuos plásticos a. polietileno tereftalato (PET) y b. polipropileno (PP)

4.2 Caracterización del eco-adoquín

La proporción de mezcla utilizada de los dos tipos de plástico para la elaboración de los eco-adoquines fue 50:50%_{PET/PP} al soportar mayor carga ante el esfuerzo a la compresión y flexo-tracción.

Esta proporción se combinó con cada tamaño del material pétreo en tres proporciones: 75:25%_{PLÁSTICO: ARENA}, 50:50%_{PLÁSTICO: ARENA} Y 25:75%_{PLÁSTICO: ARENA}. Para cada tratamiento se analizaron cinco variables y se realizaron dos repeticiones de cada una. En la Figura 5 se muestran los eco-adoquines en sus diferentes proporciones plástico: árido.



Figura 5: Eco-adoquines en sus diferentes proporciones plástico: árido

A través de la determinación del porcentaje de absorción de agua, se pudo observar que todas las proporciones presentan un índice de absorción de $\pm 1\%$, el cual se encuentra dentro de los límites permisibles bajo la NORMA ECUATORIANA INEN 3040 para adoquines de hormigón utilizados para pavimento vigente desde el año 2016 que es menor al $\leq 6\%$. Así mismo la NORMA EUROPEA UNE EN 1338 para prefabricados de cemento y hormigón manifiesta que el límite adecuado es hasta $\leq 6\%$ de resistencia climática o absorción de agua. Una absorción de agua menor que el 6% asegura una buena resistencia a bajas temperaturas y heladas. Dando como resultado que todas las combinaciones de eco-adoquines son aptas para soportar las solicitaciones requeridas en el diseño y asegurar una vida útil óptima. Los resultados se muestran en la Tabla 5.

Dentro de las construcciones agrícolas un porcentaje bajo de absorción de agua puede garantizar su uso para instalaciones como galpones, naves para almacenamiento, silos, tanques, canales conductores para riego y sistemas de riego. Un bajo porcentaje de absorción de agua determina el buen manejo de los pisos dentro de las instalaciones pecuarias y un menor esfuerzo por parte del agricultor.

Al ser la tierra una de los materiales más utilizados en los pisos de construcciones agrícolas, los eco-adoquines elaborados a partir de plástico reciclado pueden llegar a ser una alternativa económica e inocua para el mejor manejo de la finca. Pisos con cisco para evitar deslizamientos del ganado en los corrales y que a su vez absorben humedad, los cuales deben cambiarse periódicamente pueden ser sustituidos por materiales plásticos. Este tipo de eco-adoquín puede representar una alternativa a las rampas plásticas u otros materiales que pudieran salir costosas para los pequeños productores por ejemplo en la ceba de cerdos.

Tabla 5: Índice de absorción de agua (AB), densidad (ρ) y Humedad (CH%)

	Tamaño de piedra	Árido %	Plástico %	AB(%)		CH(%)		$\rho(\text{kg/m}^3)$	
				1	2	1	2	1	2
50:50 % PET:P P	Grande (± 10 mm)	25	75	0.44	0.80	16.67	10.00	1,984	1,970
		50	50	1.00	0.67	14.29	10.00	1,963	1,975
		75	25	0.97	0.65	18.75	20.00	1,965	1,977
	Mediana (± 5 mm)	25	75	0.92	0.70	16.67	12.50	1,958	1,974
		50	50	1.07	0.89	13.33	25.00	1,961	1,969
		75	25	1.00	0.63	13.33	20.00	1,963	1,978
	Pequeña (± 3 mm)	25	75	1.18	0.87	7.69	10.00	1,956	1,967
		50	50	1.08	0.72	18.00	20.00	1,958	1,975
		75	25	1.10	0.67	11.76	11.11	1,959	1,975
	Muy Pequeña (± 1 mm)	25	75	1.05	1.05	16.67	18.18	1,962	1,963
		50	50	1.00	0.83	16.67	20.00	1,964	1,970
		75	25	0.82	0.86	9.09	10.00	1,969	2,169

El ensayo de densidad formó parte del ensayo de absorción de agua. La densidad de los eco-adoquines (Tabla 5) influye directamente en su grado de resistencia frente a factores como el peso, el roce o la abrasión y depende directamente de los materiales y proporciones que fueron elaborados. En el caso de los eco-adoquines se pudo observar que los valores de densidad fueron similares al presentar una densidad $\pm 1,900$ a pesar del diferente tamaño de agregado de arena.

Esto puede deberse a que el peso y la cantidad del agregado (árido) influyen en el valor final de la densidad de los eco-adoquines. Al presentar un menor peso que equivale a un menor tamaño de partícula del agregado árido, permite incorporar una mayor cantidad de este material al eco-adoquín, mientras que, si el tamaño de partícula del agregado se vuelve más grande y pesado la cantidad que se incorpore al eco-adoquín es menor. Por lo que existe una relación inversa relacionada al tamaño de partícula y la cantidad de material árido por adoquín. Haciendo que la densidad de las diferente proporciones de plástico:árido sea similar. En la Tabla 6. Se muestra los resultados de los análisis de densidad de los eco-bloques en proporciones 50:50% PLÁSTICO: ARENA en los cuatro tamaños de partículas.

Tabla 6: Eco-bloques en proporciones 50:50% PLÁSTICO: ARENA en los cuatro tamaños de partículas

Tamaño de partícula	Mezcla	(P) (kg/m^3)	
Grande (± 10 mm)	50:50% plástico:árido o	1,963	1,975
Mediana (± 5 mm)		1,961	1,969
Pequeña (± 3 mm)		1,958	1,975
Muy Pequeña ± 1 (mm)		1,964	1,970

Realizando una comparación de los valores de densidad obtenidos en los eco-adoquines y los bloques de hormigón que van desde los 2200 – 2400 (kg/m³), se puede observar que los eco-adoquines pueden ser aptos para construcciones rurales presentando ventajas al ser más livianos y con un alto nivel de resistencia a factores climáticos y externos (calor, frío, etc), durabilidad de la estructura, adaptabilidad de formas y eliminar riesgos de sufrir deformaciones.

A través de los análisis de compresión y flexo tracción (Tabla 7) se pudo analizar que los eco-bloques presentan una buena resistencia a la compresión, presentando valores entre 18 y 25 MPa, estos datos indican que la resistencia a la compresión es independientemente a las proporciones de plástico reciclado y árido. Además, la variación de tamaño de partícula no afecto a la resistencia a la compresión. Siendo la proporción de material árido pequeño (±3 mm) la que obtuvo valores de resistencia a la compresión más altos de 22.8MPa, 23.05 MPa y 25,07 MPa para las tres proporciones: 75:25% PLÁSTICO: ARENA, 50:50% PLÁSTICO: ARENA Y 25:75% PLÁSTICO: ARENA respectivamente.

La resistencia a la flexión en los eco-bloques se encuentra en un rango de 4.27 MPa y 11.55 MPa, según los datos obtenidos se deduce que los eco-bloques con mayor porcentaje de plástico reciclado poseen valores de resistencia a flexión más altos. Esto se pudo observar en temperatura ambiente (±21C°), frío (±10C°) y calor (±30C°). Los datos obtenidos superan los establecidos en la norma española UNE 127022 para baldosas de hormigón, donde menciona que la resistencia mínima es de 3.5MPa

Según Fernández y Vilela en su estudio de resistencia a flexión de baldosas peatonales de mortero reforzado con plástico reciclado obtuvo un promedio de resistencia a la flexión de 3.66 MPa, tomando los datos a los 28 y 56 días. En un estudio de resistencia a la flexión en baldosas esmaltadas expuestas a ciclos de hielo y deshielo Flórez, Pedroza y Quintero obtuvieron un valor promedio de 24.7 MPa en cada ciclo evaluado.

Tabla 7: Resistencia a la compresión (RC) y Resistencia a la flexión y carga de rotura a temperatura ambiente (±21C°), frío (±10C°) y calor (±30C°). (RF)

	Tamaño de piedra	Piedra%	Plástico %	RC(Mpa)		RF(Mpa)		
				R1	R2	Ambiente ±21°C	Calor ± 30°C	Frío ± 10°C
50:50% PET:PP	Grande (±10 mm)	25	75	22.27	22.27	5.06	7.79	11.55
		50	50	23.10	23.10	8.96	5.22	6.46
		75	25	15.63	15.63	4.27	5.41	5.37
	Mediana (±5 mm)	25	75	19.05	19.05	6.53	4.99	5.70
		50	50	20.19	20.19	6.48	7.24	6.39
		75	25	24.99	24.99	9.03	7.51	7.63
	Pequeña (±3 mm)	25	75	25.07	25.07	9.83	5.87	10.46
		50	50	22.80	22.80	10.73	5.30	10.72
		75	25	23.05	23.05	7.03	6.69	8.31
	Muy Pequeña (±1 mm)	25	75	18.16	18.16	5.01	3.30	5.81
		50	50	21.30	21.30	9.30	6.11	6.56
		75	25	20.19	20.19	7.66	5.41	9.04

V. CONCLUSIÓN

Las obras que sirven al sector agropecuario son todas las construcciones e instalaciones que se requieren para el desarrollo de una adecuada actividad, el eco-bloque elaborado de material plástico de desecho y áridos, constituye un material pre fabricado puede ser utilizado para instalaciones pecuarias

y construcciones agrícolas y debe ser estudiando a profundidad por su incidencia en la vida del agricultor y conservación del ambiente.

Además, a través de los estudios realizados se establece dentro de parámetros de seguridad y economía y sobre la base de criterios de preservación ambiental que la mejor combinación se observó para la mezcla de PET:PP 50:50%, con un tamaño de partícula de (± 3 mm) en sus tres proporciones 75:25% PLÁSTICO: ARENA, 50:50% PLÁSTICO: ARENA Y 25:75% PLÁSTICO: ARENA

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