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A COMPARISON OF THE POTENTIAL MICROBIAL CONTAMINATION OF POLYMER-BASED AND COTTON-BASED BANKNOTES USING ATP TECHNOLOGY

Master´s thesis

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MIKROBIOLOOGILISE SAASTUSE VÕRDLUS POLÜMEER- JA PABERRAHAL KASUTADES ATP TEHNOLOOGIAT

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Author’s declaration of originality

I hereby certify that I am the sole author of this thesis. All the used materials, references to the literature and the work of others have been referred to. This thesis has not been presented for examination anywhere else.

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Abstract

In an increasingly globalized society, there is grave concern about disease transmission associated with handling contaminated banknotes. To mitigate this problem, the replacement of traditional cotton-based banknotes with polymer-based notes is now underway in many countries. Much of the available literature refers to polymer notes as superior alternative in terms of hygiene and environmental impact.

The main objective of the present study is to compare the levels of contamination of the cotton-based and polymer-based banknotes to determine which notes are the most hygienic, and to establish if ATP (Adenosine triphosphate) assay can be used to provide rapid determination of contamination of banknotes.

Samples (n = 80) were collected randomly from two cosmopolitan European capital cities –Tallinn and London. ATP assay is used as this analysis provides 'real time' estimation of contamination. The levels of contamination were determined using a Hygiena 'SystemSure' ATP meter. Contamination levels were recorded as RLUs (Relative Light Units). In this study, 100 % of tested banknotes revealed contamination. Both the £5 polymer and €5 cotton notes revealed similar hygienic status with mean RLU values of 1073 and 893 respectively. Similarly, the hygienic status of the £10 polymer and €10 cotton notes were almost the same with mean RLU values of 290 and 305 respectively.

The main observation that the levels of contamination were similar on both materials may raise doubts about the hygienic efficacy of the polymer alternative. Despite the limitations of the ATP assay, we have established that it could be used for this application. This study confirms that circulating banknotes, regardless of their material composition, are contaminated and could pose public health risks.

This thesis is written in English and is 55 pages long, including 6 chapters, 8 figures and 5 tables.

Annotatsioon

MIKROBIOLOOGILISE SAASTUSE VÕRDLUS POLÜMEER- JA PABERRAHAL KASUTADES ATP TEHNOLOOGIAT

Üha globaliseeruvamas ühiskonnas on tõsine mure saastunud rahatähtede käitlemisega seotud haiguste leviku pärast. Selle probleemi leevendamiseks asendatakse paljudes riikides traditsiooniline paberraha (puuvillast valmistatud raha) polümeerist (plastikust) tehtud rahatähtedega. Suur osa seni avaldatud kirjandusest viitab sellele, et polümeeripõhised pangatähed on hügieeni ja keskkonnamõju mõttes parem alternatiiv paberrahale. Käesoleva uuringu peamiseks eesmärgiks oli võrrelda erinevate nimiväärtustega paberist ja polümeerist rahatähtede saastatuse tasemeid, et teha kindlaks, millised on hügieenilisemad. Samuti uuriti seda, kas ATP (adenosiintrifosfaadi) analüüsi oleks võimalik kasutada rahatähtede saastumise kiireks määramiseks. Proovid (n = 80) koguti juhusliku valiku alusel kahest Euroopa pealinnast – Tallinnast ja Londonist. Kontaminatsiooni hindamiseks kasutati ATP-l põhinevat analüüsimeetodit, mis annab „reaalaja" saastumise hinnangu. Selleks kasutati firma Hygiena "SystemSure" ATP-meter seadet, mõõtmise tulemused registreeriti RLU (suhtelise valgusühiku) väärtustena. Analüüsi tulemused näitasid, et kõik testitud pangatähed olid saastunud. Polümeerist 5-naelaste ja paberist 5-euroste rahatähtede hügieenitase oli võrreldav – mõõdetud keskmised RLU väärtused olid vastavalt 1073 ja 893. Saastatuse tase oli peaaegu sama ka polümeerist 10-naelaste ja paberist 10-euroste rahatähtede puhul, millede keskmised RLU väärtused olid vastavalt 290 ja 305.

Uuringu tulemusena leiti, et paberist ja polümeerist rahatähtede saastatuse tase oli peaaegu samaväärne. See seab kahtluse alla polümeerraha kasutamise hügieenilisema alternatiivina. Vaatamata ATP-l põhineva analüüsimeetodi piirangutele leiti, et seda võib kasutada rahatähtede saastatuse tasemete määramiseks. Lisaks kinnitab antud uuring ka seda, et ringluses olevad pangatähed, sõltumata nende materiaalsest koostisest, on saastunud ja kujutavad potentsiaalset ohtu rahvatervisele.

Lõputöö on kirjutatud inglise keeles ning sisaldab teksti 55 leheküljel, 6 peatükki, 8 joonist, 5 tabelit.

List of abbreviations and terms

ATP	Adenosine triphosphate
BOPP	Biaxially Oriented Polypropylene
BoE	Bank of England
CDC	Centres for Disease Control and Prevention
CBE	Central Bank of Europe
CSIRO	Commonwealth Scientific and Industrial Research Organization
ESBL	Extended Spectrum Beta-Lactamase
FBI	Federal Bureau of Investigation
HCAIs	Healthcare Associated Infections
LCIA	Life Cycle Impact Assessment
MRSA	Methicillin-Resistant Staphylococcus aureus
NHS	National Health Service
NYU	New York University
RBI	Reserve Bank of India
RBA	Reserve Bank of Australia
RLU	Relative Light Unit
SCFs	Supercritical Fluids
SCCO2	Supercritical Carbon dioxide
TVC	Total Viable Count
VRE	Vancomycin-Resistant Enterococci
WHO	World Health Organisation

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1 Introduction

Currency[1] is one of the most frequently circulated items in the world. During its circulation, it can get contaminated and may thus play a role in the transmission of microorganisms and diseases. This concern is not new, even during the ‘black death’ - the bubonic and pneumonic plaque pandemics in Europe in the 13th Century, historical reports show that money was strongly believed to transmit fatal infections [1].

Regardless of the microbiological techniques used in the various studies, researchers investigating bacterial contamination on cotton-based notes, polymer based or coins for that matter, found significant proportions to be contaminated (53-100%) [2] – [5]. Even with the increasing use of cashless payment methods, banknotes are still one of the most commonly used and handled items worldwide, and as such are a potential vector of disease-causing micro-organisms.

The gravity of the situation can be demonstrated by several studies [1], [5] – [6] that found multidrug-resistant and virulent strains on investigated currency including Methicillin-resistant *Staphylococcus aureus* (MRSA), Extended Spectrum Beta-Lactamase (ESBL) -producing *E. coli*, and Vancomycin-Resistant *Enterococci* (VRE). These types of superbugs have the potential to cause serious infections that are very costly, hard to treat, easy to spread in healthcare and community settings, and even to transfer antimicrobial resistant determinants to other types of bacteria. In Europe, according to world health organization (WHO), the annual financial losses due to Healthcare Associated Infections (HCAIs) are estimated at approximately € 7 billion, including direct costs only and 16 million extra-days of hospital stay, 37 000 fatalities, and contribute to an additional 110 000 deaths every year [7]. More alarming, a recent study [6], found traces of *Bacillus*

[1] For the purposes of this study, the words ‘currency’, ‘money’ and ‘banknotes’ are used interchangeably to refer to the printed money notes issued by central banks and used in common dealing for purchase of items. Paper money and cotton -based banknotes are also used interchangeably.

anthracis from tested banknotes. According to the Centers for Disease Control and Prevention (CDC), spore-forming bacterium *Bacillus anthracis* is one of the most likely agents to be used in a biological attack against crops, livestock or humans. *Bacillus anthracis* is easy to acquire and disseminate or transmit from person to person. Anthrax could result in high mortality rates and have the potential for major public health impact, thus classified as a category-A priority agent for biodefense that entails special intervention for public health preparedness [8]. Considering the U.S. Anthrax mail case in 2001; known as the "*Amerithrax*" [9], the possibility of a copycat scenario where banknotes can be deliberately contaminated on a massive scale with deadly pathogens and then put back into circulation, is real.

The devastating consequences of such scenario can be demonstrated considering the 2001 Anthrax attack was carried out single-handedly by a lone person who was able to create havoc and terrorize a whole nation in what became the worst biological attacks in U.S. history. The subsequent investigation by the Federal Bureau of Investigation (FBI) and its partners has been one of the largest and most complex in the history of law enforcement [9].

The problem, therefore, is real. But, the question remains are the solutions so? The literature body is, in fact, saturated with accumulating data [1] – [6], [11] – [14], [37] – [41], that highlights the identification of a wide range of microorganisms from tested currency. However, when it comes to solutions, less attention is given as to whether these are effective or not. This one-sided approach begs the question if there is a (know-do) gap that needs bridging. The recommended solutions usually come in the form of preventive measures and typically revolve around maintaining good hand hygiene, using cashless payment methods, sterilizing banknotes, and adopting polymer-based banknotes instead of cotton-based notes.

In recent decades, unconventional more rapid methods have been developed for the real-time assessment of the microbial contamination and the cleanliness of contact surfaces. One of these technologies relies on the measurement of the bioluminescence produced by the firefly (*Photinus pyralis*) luciferase through the oxidative decarboxylation of luciferin in the presence of adenosine triphosphate (ATP) [10]. The ATP technology is used in many sectors such as the food industry, healthcare and water purification.

1.1 Research problem and scope of work

The capacity of banknotes in circulation to serve as a source of pathogenic agents represents a major challenge in the 21st century [11]. However, somewhat paradoxically, while data keep accruing to confirm the contamination of banknotes, there is a wide gap in terms of solution- oriented studies. While microbial identification studies provide very useful data as a starting point, it remains unclear if this one-sided approach is itself part of the problem. In fact, most of the published work fails to address a fundamental question: why this longstanding global issue still exists in the 21st century. But before even coming close to answering this broad question, we need to look at several factors including the type of solutions that are at our disposal, how these solutions are perceived by people and policy makers and most importantly, how efficient these solutions are. And, finally, what more can be done to help eliminate or mitigate this problem?

Much of the available literature refers to polymer notes as superior alternative in terms of hygiene and environmental impact. However, published data on the use of ATP for hygiene monitoring of banknotes are virtually non-existent and, for that matter, there is no recommendation on Pass/ Fail limits. This thesis set out to compare levels of contamination of cotton-based and polymer-based banknotes to determine which notes are the most hygienic and to establish if ATP assay can be used to provide rapid determination of contamination of banknotes.

Nevertheless, while the author attempts to discuss the arguments and controversies surrounding some of the possible solutions, the focus of the present study remains on the hygienic efficacy of the polymer alternative as one of those frequently proposed solutions which has gained momentum and wide publicity in recent years.

1.2 Objectives

The main objectives of the present study are:

- To compare levels of contamination of polymer-based and cotton-based banknotes to determine which notes are the most hygienic

- To establish if ATP assay can be used to provide rapid determination of contamination of banknotes.

Sub-aims of the current work are:

- To present some aspects of the debate and controversies that surround the polymer alternative.
- To explore the efficacy of available solutions and identify new potential ones.

- To introduce, for the first time, the concept of ATP technology as a verification method for monitoring the hygiene status of banknotes.

2 Literature overview

This section gives an overview of currency contamination as a public health concern in a global context. In addition, it provides background information about the diversity of micro-contaminants found on banknotes and describes the connection of these with HCAIs. The pros and cons of the polymer banknotes and their environmental impact are also presented.

2.1 Contaminated currency as a global problem

The capacity of banknotes in circulation to serve as a source of pathogenic agents represents a major challenge in the 21st century [11]. A joint study conducted by Queen Mary University of London and the London School of Hygiene & Tropical Medicine showed gross contamination on examined banknotes**;** in some instances, counts were as high as those expected on a dirty toilet bowl. The study concluded that by handling banknotes on daily basis, users are encountering some potential pathogens revealing faecal contamination including S*taphylococci* and *E. Coli* [12].

In a recent review [11], an extensive literature search (using PubMed, Web of Science, Google and Google Scholar databases for peer-reviewed, English-language articles with no date restrictions) concluded that bacterial contamination from 60% to as much as 100% was reported on paper currencies from different countries around the world. The review included studies conducted on Indian, Bangladesh, Iraqi and Ghanaian banknotes indicating 100% contamination by pathogenic or potentially pathogenic bacteria. Other studies conducted on Palestinian notes recorded 96.25% contamination, Columbian notes 91.1% South African notes 90%, Saudi notes 88%, and Mexican notes 69% [11]. According to the same review, currency notes in circulation revealed contamination with various microbial agents of which most are resistant to commonly used antibiotics, therefore representing risks and public health hazards to the community and individuals who handle currency notes. The review was based on more than 60 scientific sources from all around the world, most of which concluded that banknotes in circulation constitute a potential public health hazard. Furthermore, the review included several studies from US and other developed countries reporting contamination of coins and banknotes with high levels of pathogenic microorganisms, which indicates this problem is not only confined to developing nations [11].

Another international study [13] analysed a total of 1280 different currency samples from ten different countries for the presence of bacteria. The study included Australia, New Zealand, the United Kingdom, Ireland, Netherlands, Burkina Faso, Nigeria, Mexico, China and the United States. The study found one or more potentially pathogenic bacteria on tested samples as shown in (Figure 1), including:

- *Escherichia coli*,
- *Bacillus cereus*,
- *Staphylococcus aureus, and*
- *Salmonella species* [13].

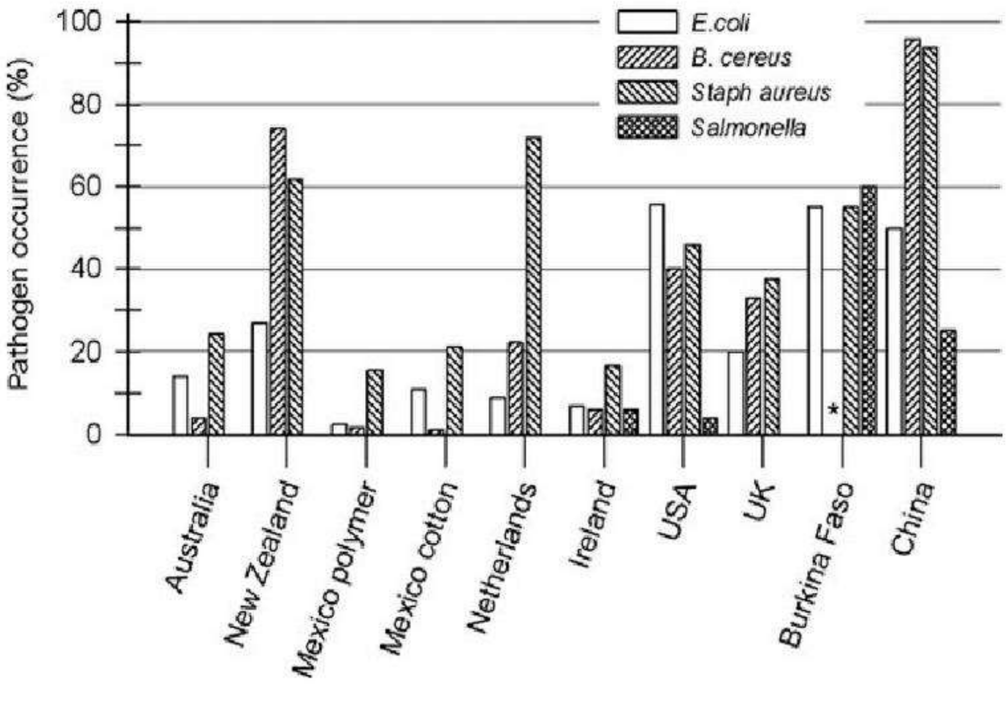

Figure 1. Pathogen occurrence on some of the world's currencies (%) [13].

The contamination percentage of banknotes by potentially pathogenic bacteria was associated with several factors including the economic prosperity of the country, the age of the banknotes, and the material of the banknotes (polymer-based vs. cotton-based) [13]. The study found that the substrate material plays a significant role in the number of bacteria found on banknotes and indicated that cotton-based banknotes had a higher bacterial count than polymer-based notes [13]. In Mexico, where banknotes of the same denomination were available in both cotton- based and polymer formats, the average number of bacteria determined on the polymer notes was approximately 25% of that found on the cotton-based notes. Figure 2 shows the number of bacteria per square cm on polymer and cotton -based banknotes on different currencies from different countries around the world [13].

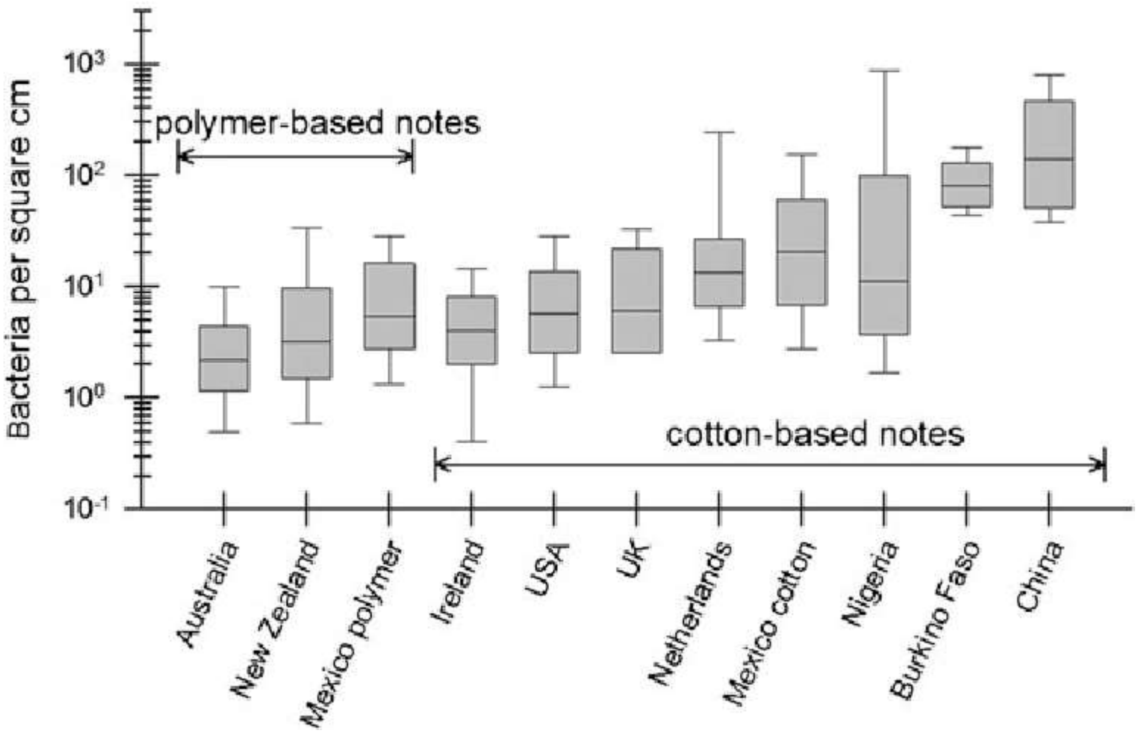

Figure 2. Number of bacteria per square cm on different banknotes [13].

2.2 The diversity of banknotes' micro- contaminants

The available literature highlights observations that a wide range of microorganisms can contaminate coins and banknotes. Researchers at New York University's (NYU) -Dirty Money Project [6] found that currency presents a medium of exchange for hundreds of different kinds of bacteria as banknotes pass from hand to hand. In their first genome study of the DNA on banknotes at NYU's Center for Genomics and Systems Biology, researchers were able to identify 3,000 types of bacteria on a set of 80 $1 bills (Cotton-linen blend) collected from a bank in Manhattan. The researchers from the NYU were able to identify many more species and types of organism than previously was possible (using traditional culture, microscopic and biochemical procedures) as they employed high-speed gene sequencing and computerized database analysis. According to the NYU's Dirty Money project [6], the most common bacterial contaminant was *Staphylococcus aureus* linked to acne and skin infections. The researchers also found *Streptococcus pneumonia* linked to pneumonia, *Helicobacter pylori* linked to gastric ulcers, *Escherichia coli* linked to food poisoning, *Corynebacterium diphtheria* linked to diphtheria, *Bacillus cereus* linked to food-borne illness and *Acinetobacter species* linked to antibiotic-resistant infections.

The dollar bills examined yielded about 1.2 billion DNA segments including 54 million segments of bacterial DNA. The range of the DNA was as diverse as New York City itself. The bulk (27-48%) of the DNA was human, but DNA from dogs, horses and white rhino was also present. DNA from all microbial groups was evident, including bacteria (including those responsible for anthrax and diphtheria), viruses, fungi and plant pathogens [6].

One earlier study found 94% of 68 US one-dollar cotton-based notes to be contaminated with pathogenic or potentially pathogenic micro-organisms that can cause both community and hospital acquired infections [14]. Given the US Dollar is probably the most popular global currency; the NYU's findings [6] have once more confirmed that contaminated currency is an international problem, not just a national one.

2.3 Banknotes and Health Care Associated Infections (HCAIs)

A recent review of available literature has again highlighted the potential of banknotes and coins to carry bacteria and fungi, and their potential to spread HCAIs - particularly when handling money is coupled with the simultaneous handling of food [15].

Another international study [5] investigated the survival rates of ESBL-producing *E. coli*, MRSA and VRE on various bank notes from around the world including the Euro, US Dollar, Canadian Dollar, the Indian Rupee and Moroccan Dirham. The study found that MRSA and VRE survived on tested samples at variable rates. VRE was isolated from some tested notes after one day of drying. Given that Vancomycin is one of the last line antibiotics for treating multidrug resistant infections, this finding is very alarming in terms of its serious implications considering that some of the tested currencies are among the most circulated currencies in the world. [5].

According to the WHO, HCAIs are the most frequent adverse events in healthcare delivery and no country or institution can claim to have solved the problem yet. Every day, HCAIs result in increased resistance of microorganisms to antimicrobials, long-term disability, prolonged hospital stays, massive additional costs for health systems, high costs for patients and their families. In Europe, the losses due to HCAIs are estimated annually at approximately € 7 billion and contribute to more than 110 000 deaths every year [7]. In the USA, the annual economic impact was estimated at approximately US$ 6.5 billion in 2004 with approximately 99 000 attributable fatalities in 2002 [7].

More recent data estimates the cost of antibiotic resistance to the economy in the U.S at $20 billion annually in excess direct health care costs, with an additional burden of $35 billion in lost productivity [16]. However, the full magnitude of the problem and its true global burden remains unclear due to difficulties in gathering reliable data particularly in developing countries as a result of lacking efficient surveillance systems [7].

2.4 Pros and Cons (polymer-based vs. cotton-based notes)

2.4.1 Cost advantage

The main reasons countries are opting for polymer currencies are security and durability. Moreover, there is a crucial economical advantage in the long run. Although the upfront cost of producing polymer banknotes is higher than the typical cotton-based notes that most countries still use today, polymer banknotes can be economical in the long run. According to the Bank of England (BoE), the move to the polymer alternative will save 100 million pounds over a decade [17].

While polymer banknotes are increasing in popularity, not all central banks are fully convinced of the benefits of switching to polymer. One reason could be the *'conservatism'* of central banks [18]. Decision makers consider shifting to polymer a huge risky move. Therefore, many central banks are simply waiting other countries to switch to polymer and see what happens before they make a costly move. The higher upfront production cost could present a short-term burden for developing countries since the saving advantages from the extra durability only befall over time [18].

2.4.2 Security features

Polymer banknotes incorporate high-tech security features such as holograms and see-through windows that contain hard-to-forge images. By shifting to polymer, central banks worldwide will be able to combat the menace of counterfeiting more effectively and ensure proper and prompt reporting of counterfeit notes. It allows easer detection and verification and slows down the circulation of faked notes, which plagues many countries [18].

For instance, in India, during 2016-17 a total 762,072 pieces of counterfeit notes were detected in the banking system, of which 32,432 pieces (4.3 per cent) were detected at the offices of the Reserve Bank of India (RBI) while 729,640 pieces (95.7 per cent) were detected by commercial banks as shown in Table 1 [19].

Table 1. Number of counterfeit notes detected RBI Annual Report 2017 [19].

Year	Detection at Reserve Bank	Other Banks	(No. of pieces) Total
1	2	3	4
2014-15	26,128	568,318	594,446
	(4.4)	(95.6)	(100.0)
2015-16	31,765	601,161	632,926
	(5.0)	(95.0)	(100.0)
2016-17	32,432	729,640	762,072
	(4.3)	(95.7)	(100.0)
Note: 1. Figures in parentheses represent the percentage share in total. 2. Does not include counterfeit notes seized by the police and other enforcement agencies.			

2.4.3 Durability and increased life-span

Another advantage of the polymer-based notes is durability and increased life-span. Polymer notes last longer than paper notes by at least 2.5 times. Furthermore, it's claimed to survive extreme weather conditions [18], [20]. However, the change to polymer notes has not always gone without incident.

There have been instances where polymer notes have been affected by extreme heat in some countries. For instance, one of the reasons that led the Central Bank of Nigeria (CBN) to resolve to discontinue printing the naira in polymer notes was that the ink on their polymer notes faded under the blazing sun and searing heat experienced year-round in the African country. The notes began smearing quite badly which led bus conductors and major merchants in the country to reject the blurred polymer notes. 1n 2001, the Central Bank of Bangladesh also decided to go back to cotton notes after a short trial with the 10Taka polymer note. In 2006, the Solomon Islands also reverted to cotton-based notes [18].

2.4.4 Environmental impact

Cotton based banknotes are comprised mainly of cotton (75% by composition) [21] – which require large quantities of pesticides and water to produce. On the other hand, the base material of polymer is a non-renewable resource, but it can be easily recycled at the end of the life cycle by polymer recyclers into other useful plastic products resulting in a second life cycle and subsequently a lower environmental impact [20], [22].

Moreover, polymer- based banknotes have a longer lifespan compared to paper banknotes by at least 2.5 times [18], [20], [22]. This advantage over cotton notes plays a key role in reducing the need and the frequency of producing new replacement. Subsequently, this is a major factor in lowering many of the environmental problems associated with the disposal of cotton- based banknotes. Table 2 shows the stages of the Life Cycle (LC) for both types of notes and illustrates that polymer notes can be easily recycled at the end of their life cycle as useful feed stocks for consumers, while cotton based notes end up causing higher environmental impacts in terms of incineration and landfill [AS/NZS ISO 14040:1998; Life Cycle Assessment (LCA), TUV Rheinland, Sicherheit und Umweltschutz, 2005] [20].

Table 2. Life Cycle Analysis of polymer-based and cotton-based banknotes [20].

	1	**2**	**3**	**4**	**5**	**6**	**7**
Life Cycle Stage	Production of raw material	Initial conversion of raw material	Secondary conversion to substrate material	Manufacture of banknotes – printing and finishing	Banknotes in service	Withdrawn and cancelled	Final disposal
Polymer	Extraction and refining of petroleum	Synthesis of poly-propylene	Extrusion & rolling of polypropylene film	Gravure, offset, intaglio, numbering, over coating, guillotining, sorting	Mean service life 5 times that of paper banknotes	Granulated and mixed	Recycled as feed stock for consumer products
Paper	Growing cotton and cleaning raw cotton	Production of cotton combers / Collection of rags	Manufacture of rag fiber paper	Offset, intaglio, numbering, guillotining, sorting	Mean service life set as the standard for comparison	Granulated and mixed for landfill OR bundled for incineration	Secure landfill disposal OR incineration

The Reserve Bank OF India (RBI) also engaged the services of The Energy and Resources Institute (TERI) to study the carbon footprint of cotton-based banknote vis-à-vis polymer -based substrate and assess their overall environmental impact. The findings indicated that replacing the cotton-based notes with polymer would attract substantial environmental benefits [23].

The Reserve Bank of Australia (RBA) also announced that polymer banknotes are more durable, cleaner and more hygienic than paper banknotes, and can be recycled at the end of their life cycle into a range of useful plastic product [24].

In a very recent study in Mexico (Luján-Ornelas, Mancebo del C. Sternenfels and Güereca, 2018) conducted a life cycle impact assessment (LCIA) in which they compared polymer banknotes with cotton notes since the circulating Mexican banknotes include the two types of materials concurrently.

The study was conducted based on ISO 14040/44 (ISO, 2006) to evaluate the environmental impacts of the two substrates. According to the study [25], banknotes printed on polymer substrates posed lower environmental impacts.

The findings favoured the polymer banknotes over the cotton based mainly because of the longer lifespan of the polymer substrate; yet, it was found that there is still a considerable environmental impact by the polymer at the stage of the extraction of the raw materials (crude oil) and during manufacturing as well as throughout the distribution stage.

Concerning microbial contamination of Mexican banknotes, in an earlier study it was found that the average number of bacteria determined on the polymer notes was approximately 25% of that found on the cotton-based notes [13].

The complete life cycle of the two different types of substrate was considered in [25] from the extraction of the raw materials stage, through different processes of manufacturing, distribution and the usage stage, up to the return of unfit banknotes to the central bank of

Mexico, and their subsequent destruction and final disposal at the end of their useful life as illustrated in Figure 3 [25].

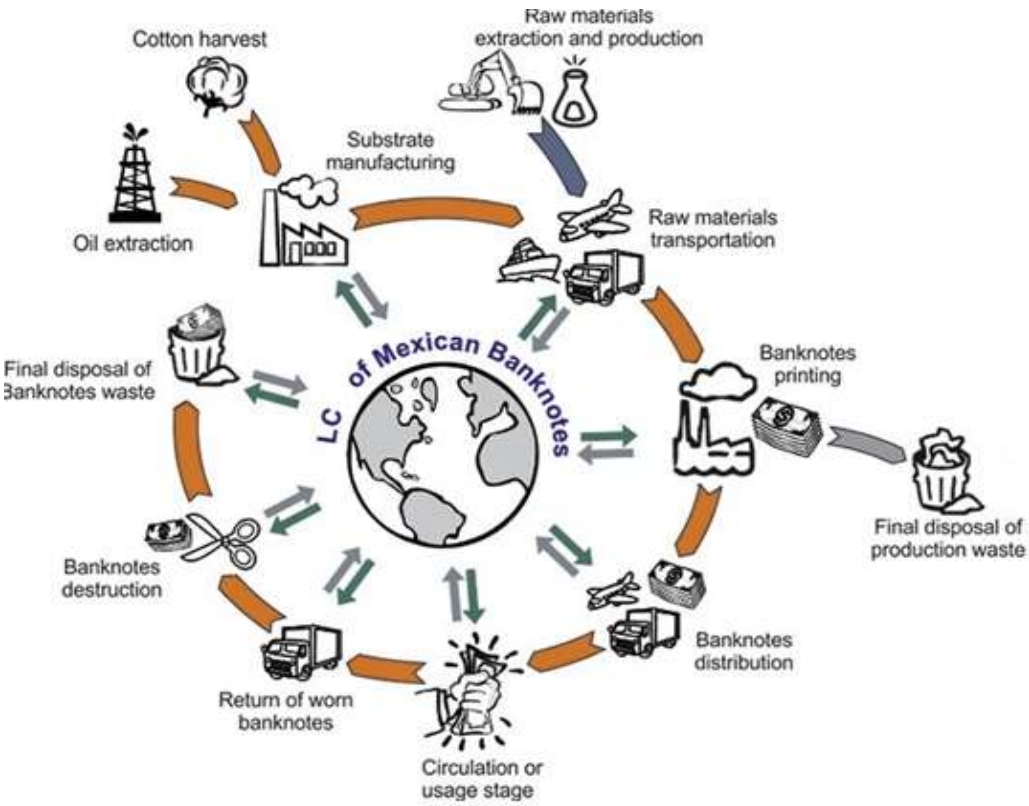

Figure 3. The complete life cycle of the Mexican banknotes (adapted from [25]).

Concerning the cotton- based notes, the main impact was found to be associated with the extraction of the raw materials, followed by the distribution stage of the notes. In terms of electricity consumption, the inclusion of the automatic teller machines (ATMs) in the LCIA of banknotes revealed that the electricity required by the ATMs was a major contributor to the environmental impacts for both types of notes. For both types of banknotes, the stages of the life cycle that refer to the extraction of the raw materials, combined with the average lifespan of the banknotes and the electricity consumption during the usage stage, were the determinant factors in the total environmental impact associated with the Mexican banknotes. Subsequently, it was found that the longer average lifespan of the polymer note is a key factor in lowering the environmental impacts of the banknotes.

The evaluated categories of the LCIA included, but was not limited to, agricultural land occupation (ALO, in m2 × yr.), climate change (CC, in kg CO2 to air), fossil resource depletion (FD, in kg oil), mineral resource depletion (MRD, in kg Fe), and water depletion (WD, in m3). In all categories investigated in the study, the banknotes printed on polymer revealed a better environmental performance than the banknotes printed on cotton- based notes. The category with the most significant difference was WD followed by ALO as shown in Figure 4 [25].

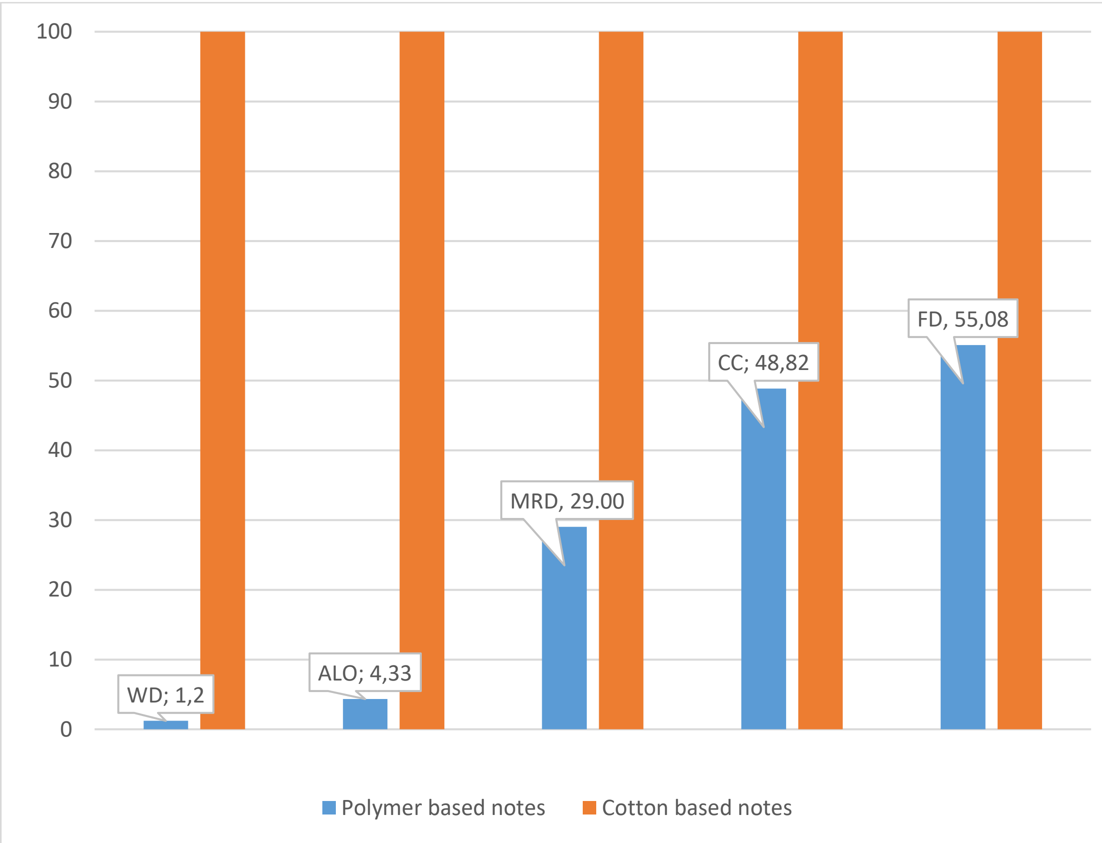

Figure 4. Categories of life cycle assessment LCIA showing the most significant difference in WD water depletion and agriculture land occupation ALO (adapted from [25]).

The study [25] concluded that the use of polymer in the manufacturing of banknotes leads to both a reduction of pollutant emissions to the environment and a decrease of the depletion of natural resources. These findings are basically consistent with [20], [22] – [24].

Overall, there is a strong evidence that banknotes printed on polymer substrate present lower environmental impacts. Furthermore, at the end of their useful LC, polymer notes can be recycled into useful plastic products such as plumbing fittings, compost bins and other industrial or household products. However, some less developed countries may not have the adequate recycling technologies or facilities - and thus by burning these products; they end up causing more pollution. All the inputs and outputs of each individual process, including the required transportation was considered as illustrated in Figure 5, which also shows that both types of materials have substantial impacts in terms of air emissions, soil releases and wastewater discharges.

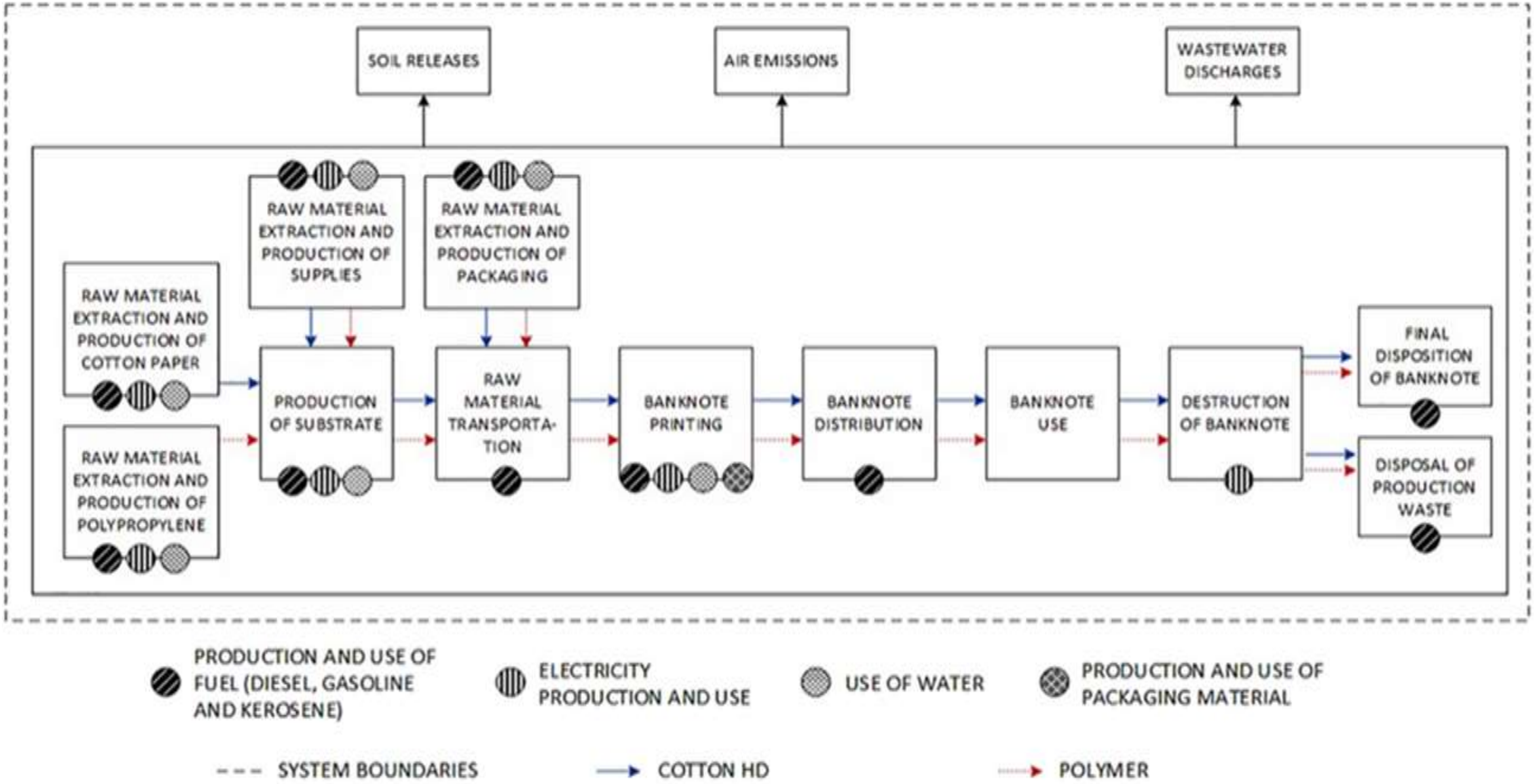

Figure 5. Both types of materials have substantial impacts in terms of air emissions, soil release and wastewater discharges (2018) [25].

3 Current solutions and prevention measures

The capacity of banknotes in circulation to serve as sources of pathogenic agents represents a major challenge in the 21st century [11]. To respond to this challenge, several preventive measures have been proposed. These counter measures include regular cleaning of the currency in banks and cash machines by means of supercritical fluids (SCFs), UV light, supersonic, hand hygiene, contact-less transactions and producing bank notes from materials with antimicrobial features which inhibit bacterial growth, have all been proposed.

3.1 Supercritical Fluids (SCFs) for cleaning of banknotes

The continuous circulation of currency results in its soiling and subsequently leads to rejection by the fitness sorting machines. Unfit banknotes must be withdrawn from circulation and replaced with new notes. According to data from the De Nederlandsche Bank, 60−80% of banknotes tested for fitness around the world are classified as unfit due to soiling [26].

A published study in 2013 [27] showed that supercritical fluids (SCFs) technology, utilizing substances that maintain gas and liquid properties through manipulation of their pressure and temperature, could be effectively applied on banknotes to remove soiling, human grease and other oils and contaminants such as common bacterial colonies and pathogens. According to the same study, the annual replacement orders by the Federal Reserve Bank to the Department of the Treasury and the Bureau of Engraving and Printing (BEP) to produce replacement notes can range from 7 to 11 billion in the United States only. The cost of replacing unfit banknotes is estimated at US$10 billion with nearly 150 billion new banknotes being manufactured and printed worldwide each year. In addition, central banks must also deal with the environmental impact of disposing of nearly 150,000 tons of banknotes classified as unfit for recirculation each year [27].

The study [27] showed that Supercritical Carbon dioxide (SCCO2) can be effectively utilized for decontamination of banknotes. The system as shown in (Figure 6) uses an externally wrapped thermal heating tape where the cell could be operated at pressures up to 2000 psi and in the range of temperatures from 25−60 °C. To enhance the cleaning process, the cell could be also immersed in an ultrasonic agitation bath. A newer generation of decontamination cell was developed with the pressure limit up to 10,000 psi and equipped with additional inlet and outlet ports and a liquid CO2 pump to permit CO2 flow though the cell when the latter was pressurized.

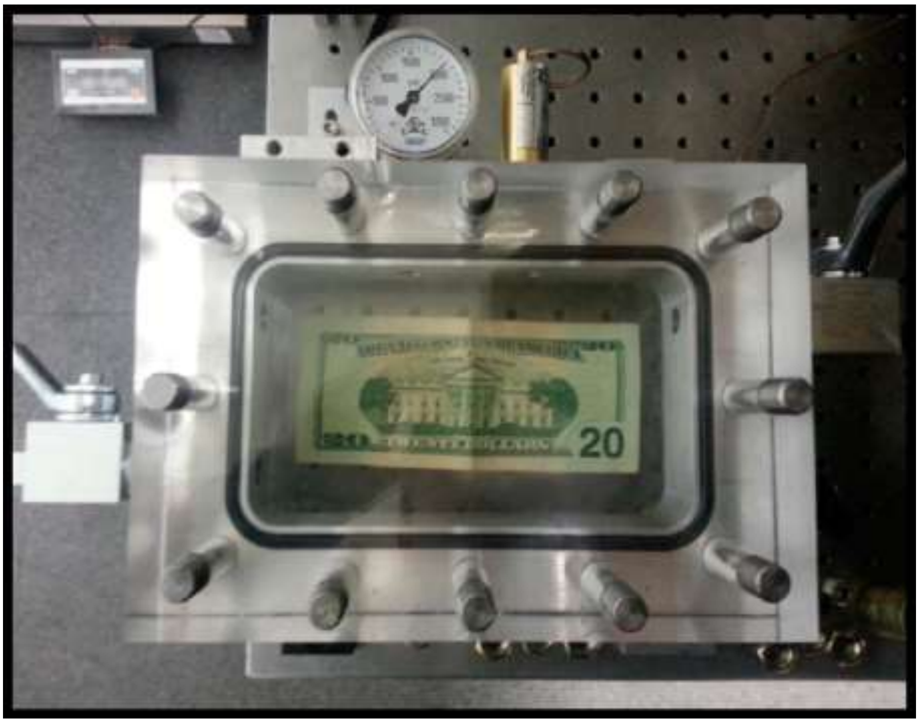

Figure 5. High pressure CO2 cell in the supercritical phase (60 °C, 2000 psi) [27].

More importantly, the study [27] showed that the cleaning process of banknotes using the SCCO2 technique could be achieved without jeopardizing the integrity of the sophisticated and costly security features employed by central banks to avert counterfeiting such as security threads, watermarks, ultra-violet (UV) ink and holograms. In addition to its claimed effectiveness with both cotton and polymer-based notes, the SCCO2 cleaning system also showed that bundles of 100 banknotes could be cleaned together, rather than one banknote at a time, which makes it very appealing for central banks. The ability to use SCCO2 treatment for traditionally strapped and bundled notes offers many logistical advantages and eliminates the necessity for new equipment that would have to be developed to load enormous numbers of individual notes into slots for cleaning.

Measurements of note soiling distributions on tested banknotes showed a significant shift in soiling levels after processing with SCCO2 which supports the claim that the technique is effective in the removal of sebum and other soiling agents which leads to significant reduction in the number of notes being classified as unfit due to soiling.

Furthermore, samples of banknotes were also tested to determine the efficacy of the SCCO2 process in removing common microbial colonies; swab tests were conducted on United States $1 bills and colonies of both micrococcus luteus (1 colony/swab) and yeast (234 colonies/swab) were cultured at 35 °C in MacConkey media. Subsequently, the tests revealed zero colony counts for both types of organisms after cleaning with SCCO2 [27]. However, the experiments were performed on a number of banknotes with a focus on United States banknotes which are cotton based (75% cotton and 25% linen fibres) [21]. Therefore, it remains unclear if the efficacy of the SCCO2 technique would be the same for the decontamination of polymer -based banknotes. The study states that the SCCO2 method works effectively with both cotton and polymer-based notes; however, the experiment was conducted in 2013 and it is unclear if the £5 sampled in the study was cotton or polymer -based since the £5 polymer-based note was only introduced in in September 2016 [17]. Therefore, the efficacy of the SCCO2 technique on polymer banknotes should be clarified explicitly. In any case, according to the same study [27], while cleaning of the banknotes allows for the mitigation of the spread of disease to individuals processing currency, it does not keep them clean once these are put back into circulation.

3.2 The trend for the polymer alternative

In recent years, the replacement of traditional cotton- based notes with polymer based has gained momentum and become a trend. Several sources [11], [13], [17] – [18], [20], [22], [24] recommend polymer-based notes as a better alternative since their benefits include greater durability, better security measures and cost-effectiveness; and they are perceived to be more environmentally friendly and more hygienic.

Although the primary purpose for the development of polymer substrates for banknotes was to combat counterfeiting and to improve security, there is strong evidence that the Biaxially Oriented Polypropylene (BOPP) material that the polymer–based banknotes are made of, provides other advantages i.e. more durable than cotton-based notes, more resistant to soiling and folding, non-porous, and it does not absorb sweat or water [20]. Given these characteristics, polymer banknotes could be more hygienic than cotton based. Several studies have shown that polymer-based banknotes often have a relatively low bacterial count compared with the cotton-based banknotes. This may be due to various physicochemical parameters of polymers [13], [20]. Thus, polymer-based notes are becoming a global trend.

The replacement of cotton-based banknotes with polymer-based notes is now underway in many countries. In 2011, according to estimates of the Commonwealth Scientific and Industrial Research Organization (CSIRO), there were over thirty different denominations in service in 22 countries (Table 3) tallying some 3 billion polymer notes worldwide [18].

Table 3. Countries issuing Guardian polymer (1988 – 2013) as updated on March 2014 [18].

Country	First	Unit of Currency	Denominations
Australia	1988	Australian dollar	$5, $10, $20, $50, $100
Papua New Guinea	1991	Papua New Guinean kina	K2, K5, K10, K20, K50, K100
Singapore	1991	Singapore dollar	S$2, S$5, S$10, Commemorative S$50 (1990), S$20 (2007)
Brunei	1996	Brunei dollar	B$1, B$5, B$10, B$50, B$100, B$500, B$1000, B$10000, Commemorative B$20 (2007)
Malaysia	1998	Malaysian ringgit	RM1, RM5, Commemorative RM50
New Zealand	1999	New Zealand dollar	NZ$5, NZ$10, NZ$20, NZ$50, NZ$100 Commemorative $10 (2000)
Romania	1999	Romanian leu	1L, 5L, 10L, 50L, 100L, 200L, 500L, 10,000L, 50,000L, 100,000L, 500,000L, 1,000,000L Commemorative 2000L (1999)
Vietnam	2001	Vietnamese dong	10,000, 20,000, 50,000, 100,000, 200,000, 500,000, Commemorative 50 (2001)
Mexico	2002	Mexican peso	$20, $50, Commemorative $100 (2009)
Chile	2004	Chilean peso	$1000, $2000, $5000
Guatemala	2007	Guatemalan quetzal	Q1, Q5
Hong Kong	2007	Hong Kong dollar	HK$10
Nigeria	2007	Nigerian naira	N5, N10, N20, N50, Commemorative N50 (2010)
Israel	2008	Israeli new shekel	NIS20
Nicaragua	2009	Nicaraguan cordoba	C$10, C$20, C$200, Commemorative C$50 (2010)
Paraguay	2009	Paraguayan guarani	G2000 G5000
Dominican Republic	2010	Dominican peso oro	RD$20
Honduras	2010	Honduran lempira	L20
Vanuatu	2010	Vanuatu vatu	VT200, VT1,000, VT2,000, VT10,000
Canada	2011	Canadian dollar	$5, $10, $20, $50, $100
Costa Rica	2011	Costa Rica colones	₡1000
Mozambique	2011	Mozambique metical	20MT, 50MT, 100MT
Mauritius	2013	Mauritian rupee	Rs25, Rs50

From 1988 - 2013, the number of countries that issued polymer notes printed on Australian-made *guardian* polymer substrates has increased to reach twenty-nine [18]. In the UK, the BoE introduced the £5 polymer-based note in September 2016, and the £10 note in September 2017; a new £20 polymer note is due for introduction in 2020 [17].

More recently, on 1 January 2018, the Central Bank of Mauritania joined the polymer trend and issued a new polymer banknote series. Mauritania is the first country in Africa to issue a whole series of banknotes on *Guardian* polymer [28]. However, the number of countries (Table 3) using *Guardian* polymer has considerably decreased compared to number of countries that are currently using it as updated on 2018 (Figure 7) which may reflect some aspects of the debate and uncertainties that are surrounding the polymer alternative.

Figure 6. Countries currently using polymer banknotes as updated on 2018 [28].

3.3 Monopolistic situation

Moreover, on the drawbacks side, there seems to be strong evidence on a monopolistic situation governing the production technology of polymer banknotes. The production and supply of the *guardian* substrates are a lucrative business for the Reserve Bank of Australia (RBA); and to secure contracts for their *guardian* - polymer substrates, some Australian parties were found to be engaged in irregular deals with high officials in many countries [29].

This has become evident from the 29 July 2014 *Wikileaks* release of a gagging order by the Australian Supreme Court. The case concerned allegations of multi-million inducements made by officials of the (RBA) subsidiaries *Securency* and Note Printing Australia (NPA) to secure contracts for the supply of Australian-style polymer- bank notes to the governments of Vietnam, Malaysia, Indonesia, and other countries [29].

3.4 Hybrid notes as a new rival

The security gap between cotton-based and polymer notes is closing and it is now possible to make “hybrid notes”. The hybrid notes not only feel like paper notes, but also combine the security advantages of polymer substrates such as the security threads, embedded watermarks and machine-readable elements, in an innovative combination of protective polyester film around a cotton fiber core [30].

The hybrid notes are already in circulation in many countries around the world including Bulgaria, Bhutan, Jamaica, and Kazakhstan. On July 18, 2018, the South African Reserve Bank (SARB) issued a commemorative banknote series with five denominations in total. Two of these, the 20-rand and 10-rand notes, were printed on Hybrid substrate from *Louisenthal*, a cotton substrate coated on both sides with polyester foil. The robustness of Hybrid banknotes makes them especially suited for countries with a diversity of climates such as South Africa [31].

3.5 The hygienic controversy over the polymer alternative

According to [11] [13], [17] – [18], [20], [22], [24] polymer-based notes offer a better alternative as their benefits include greater durability, better security measures, cost-effectiveness and more environmentally friendly. Polymer notes are widely avowed to be cleaner and more eco- friendly compared to cotton-based notes. Paper bank notes are made of a rugged mix of 25% linen and 75% cotton or 100% cotton which allow more surface area for diverse microorganisms to accumulate within. Furthermore, the rugged texture of cotton- based notes was shown to accommodate not only germs but chemicals as well [32].

On the other hand, polymer–based banknotes are made of BOPP - based substrate and thus have a relatively smoother, non-fibrous and non-porous surface which reduces bacterial attachment, compared to that observed on the fibrous surfaces of the cotton-based notes [13], [20], [21] – [22], [24].

However compelling the argument is for polymer-based bank-notes, some studies continue to show there is cause for concern: research in Australia (one of the first countries in the world to shift to polymer-based banknotes), found that cash and credit cards continued to be a potential source for bacteria as in the worst example $10 note had a contamination count which is 6.4 times higher than the average count from similar tests on public lavatory seats [32]. Another study [5] found that some types of bacteria including *Staphylococcus aureus* and *Escherichia coli* survived longer on polymer-based bank notes than cotton-based ones; and that the polymer structure allowed for the growth and transmission of multi-drug resistant pathogens Vancomycin-Resistant *Enterococci* (VRE). These findings could have significant implications regarding the global spread of such pathogens, particularly with currencies such as the $US and the Euro which are widely used and circulated world-wide [5].

4 Materials and Methods

This section introduces the ATP assay for the hygiene monitoring of banknotes and gives details of the collected samples, geographic coordinates and the testing technique.

4.1 ATP assay for banknotes hygiene verification

The ATP assay has been used for over 30 years as a direct and rapid test to verify cleanliness in many sectors such as the food industry, healthcare and water purification. ATP assay is recognized by the CDC in USA, NHS Research Institute, Department of Health and Health Protection Agency's Rapid Review Panel in UK, Danish and Swedish Standard for Hospital cleaning and Infection control DS 2451-10 2011 [33].

The benefits of using adenosine triphosphate (ATP) technology for a rapid and objective verification of cleanliness have already been demonstrated and widely acknowledged. Table 4 [34] presents, side by side, a non-exhaustive list of its advantages over traditional microbiology testing.

In all indicators, the ATP method indicates similar or superior performance except for the specific detection of microbial matter, which is not of a much concern for the purposes of the current study.

Table 4. Advantages of the ATP method over traditional microbiology (adapted from [34]).

Method	ATP Monitoring	Microbiology Testing
Ease of use	★★★	★
Objective	★★★★	★★★★
Specific	★	★★★★
Quantitative	★★★★	★★★★
Qualitative	★★★★	★★★★
Timeliness	★★★★	
Low Cost	★★	
Training Tool	★★★★	★
Management Tool	★★★★	★★★★
Fraud-Proof	★★★★	★★★★
Software Analysis	★★★★	
Grand Total	**38**★	**26**★

4.2 Sample Collection

Banknotes were collected from two European capital cities – London and Tallinn.
Table 5 shows banknotes, denominations and the material they made of. Samples were collected randomly from a variety of locations including retail outlets, restaurants and healthcare premises.

All banknotes used in this study were taken out of normal circulation from both cities. Damaged and defaced notes were not included in the study.

Table 5. Currencies and their material and denominations sampled in this study.

City	Currency		Banknote Substrate	Tested Denominations
	Name	Symbol		
Tallinn	Euro	€	Cotton-based	€5 (*n =20*)
London	Pound	£	Polymer-based	£5 (*n =20*)
Tallinn	Euro	€	Cotton-based	€10 (*n=20*)
London	Pound	£	Cotton-based	£10 (*n =20*)

A total of 40 polymer-based banknotes (£: GBP), including £5 (N=20) and £10 (N=20) notes, were collected in London. Each note was individually packed in a sterile polyethylene bag and labelled with the source, date of collection and serial number, and submitted to the laboratory for analysis.

A total of 40 cotton-based banknotes (€: Euro), including €5 (N=20) and €10 (N=20) notes, were collected in Tallinn. Each note was individually packed in a sterile polyethylene bag and labelled with the source, date of collection and serial number and submitted to the laboratory for analysis.

4.3 Geographic coordinates

Tallinn is the capital and largest city of Estonia. It is located on the northern coast of the country, on the shore of the Gulf of Finland at 59° 26’ 13.06” N and 24° 45’ 12.71” E [https://www.gps-coordinates.net]. According to the preliminary estimate of Statistics Estonia, the population of Tallinn on 1 January 2018 was 430,805. [https://www.stat.ee/population].

London is the capital and largest city of both the United Kingdom and England. It stands on the River Thames in south-eastern England at 51.5074° N and 0.1278° W [https://www.gps-coordinates.net]. Its population at 30 June 2015 (the most recent year of data available) was estimated to be 8,674,000 inhabitants [35].

4.4 Sample testing

ATP assay was used as this analysis provides ‘real time’ estimation of contamination (within 30 seconds of sampling): traditional culture and identification methods are time- and labor-intensive, while more recent analytical techniques such as high-speed gene sequencing and computerized database analysis require specialist laboratory facilities.

Upon receipt at the laboratory, the obverse side of each note was swabbed with a ‘Suresnap’ ATP assay device, and the level of contamination determined using a Hygiena ‘SystemSure’ ATP meter. Each contamination level was recorded as an RLU [Relative Light Unit]value. The meter, the swabbing device and the swabbing technique were all used according to the manufacturer guidelines [36].

The swabbing device was allowed to equilibrate to room temperature (21 – 25 °C) before use. The sample surface was thoroughly swabbed, rotating the swab to maximize sample collection. Adequate pressure to flex was applied and swabbed in a crisscross pattern vertically, horizontally, and in both diagonal directions. The sampling device was activated.

The swab bud was bathed in liquid by shaking for 5 – 10 seconds to activate the sampling device. Once activated, the swab had to be placed in the luminometer within 30 seconds. The swabbing device was inserted into Hygiena luminometer. The measurement was initiated, and the results recorded. Each contamination level was recorded as an RLU [Relative Light Unit] value.

An RLU result is directly proportional to the amount of ATP collected from the sample; so, the greater the RLU value, the greater the level of contamination of the surface. ATP does not differentiate between microbial and non-microbial ATP, however any ATP on a surface has the potential to support microbial growth.

5 Results and Discussion

This section presents the results, explains and compares them with the findings from other studies. Comments on the significance of the study, its implications and limitations are acknowledged. Current and possible novel solutions and control measures are also critically evaluated and discussed in a wider context.

5.1 Results

The results reported in this study revealed that all tested samples were found contaminated (100%) recording failed ATP scores i.e. higher than 30 RLUs. Both the £5 polymer and €5 cotton notes were of similar hygienic status with mean RLU values of 1073 and 893 respectively. Similarly, the hygienic status of the £10 polymer and €10 cotton notes were almost the same with mean RLU values of 290 and 305 respectively; however, these higher denomination notes were more hygienic (less contaminated by ATP) than the £5 and €5 notes as shown in Figure 7.

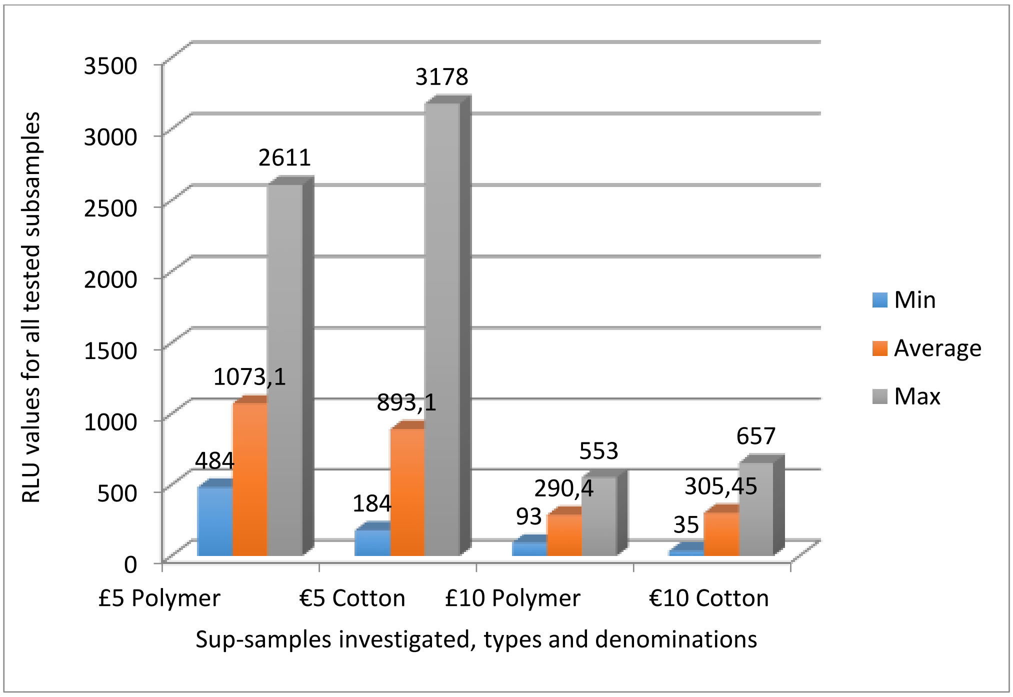

Figure 7. RLUs with mean values for tested sub samples

The box and whiskers plot (Figure 8) display the distribution of the RLUs. The box represents the interquartile range (central 50%) of the RLUs values of the banknotes, the whiskers represent either the upper or lower 25%. Number of banknotes sampled per subsample: N = 20).

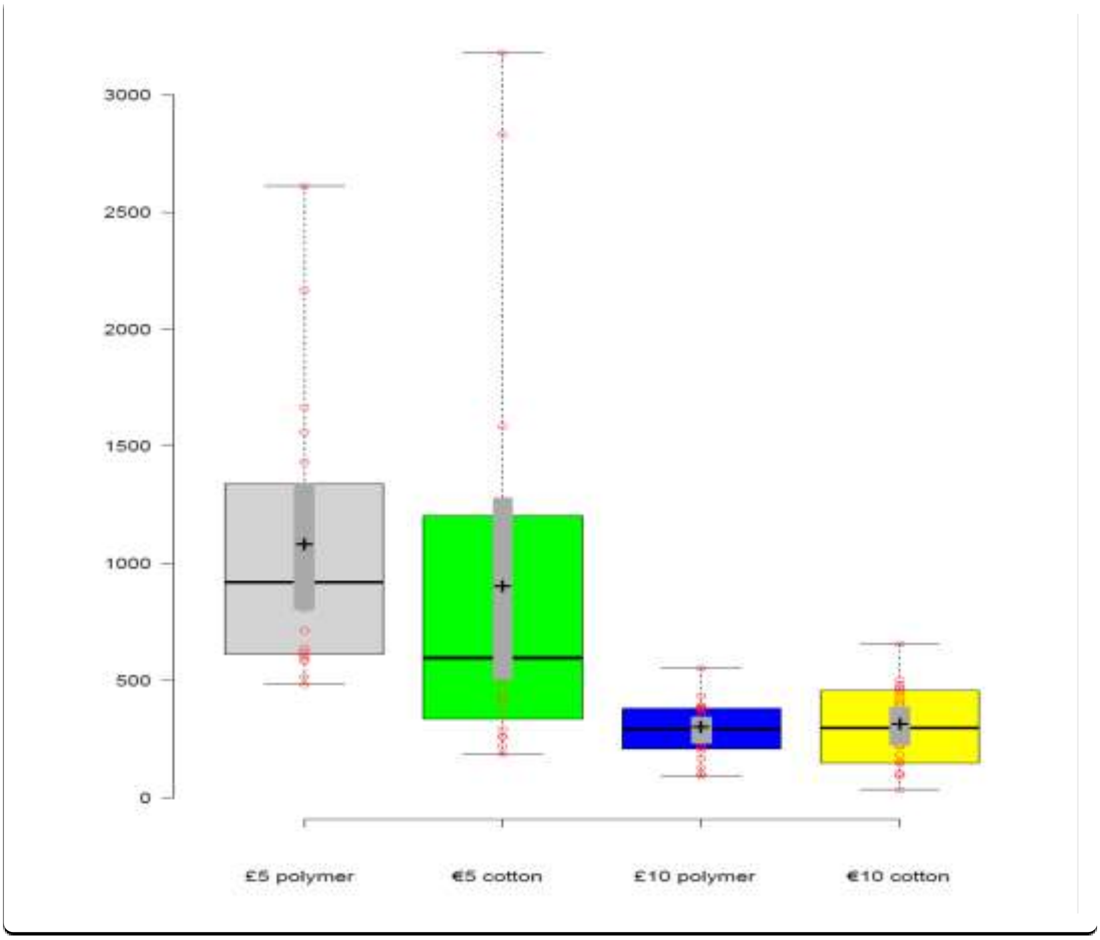

Figure 8. Box and whisker plot displaying distribution of RLUs

5.2 Discussion

5.2.1 Main outcomes

Eighty samples of banknotes (40 Polymer- based and 40 Cotton- based) were analyzed for their hygiene status and potential microbial contamination using ATP assay. Hygiena systems used in this study come predetermined with Pass and Fail limits of 10 and 30 respectively. Any score of <10 RLU is a Pass. Scores from 11 to 30 RLU are regarded as a Caution and any score >30 RLU is regarded as a Fail [33]. For the purpose of this study, the Caution area was eliminated. Pass and Fail limits were both set to 10 and 30 respectively.

In the present study, all tested samples were found contaminated (100%) recording failed ATP scores i.e. higher than 30 RLUs. These results were in line with previous reports from other countries which elucidated that banknotes are often contaminated with one or more bacterial species including a recent study that found all tested samples (100%) were contaminated [2], [4]. Other studies also found a significant proportion of the investigated samples (53% - 100%) to be contaminated [3], [11].

In Estonia, the findings are also supported by a very recent study on the microbial contamination of the euro currency detailing the prevalence of bacterial contamination on coins and banknotes and the risks of handling money, which concluded that different bacteria originating from both human body and environment can be found on currency which can be a potential carrier of infectious agents [37].

These findings are also supported by other studies from different parts of the world [1] – [6], [11] – [15], [38] – [42] concluded that paper currency is one of the potential vectors to transmit diseases and attributed this to the fact that banknotes, as a medium of exchange, continuously pass through different hands which increase the possibility of transferring pathogenic microorganisms and thus cross-contamination.

Based on available literature, the theory that banknotes in circulation are potentially contaminated with pathogenic micro-organisms has already been well documented. However, the results of our study are significant as these do not agree with other studies stating that polymer notes are more hygienic than cotton-based notes – but found that levels of contamination were similar on both materials. The results reported in this study are noteworthy as both the £5 polymer and €5 cotton notes were of similar hygienic status with mean RLU values of 1073 and 893 respectively. Similarly, the hygienic status of the £10 polymer and €10 cotton notes were almost the same with mean RLU values of 290 and 305 respectively; however, these higher denomination notes were more hygienic (less contaminated by ATP) than the £5 and €5 notes.

The replacement of cotton-based banknotes with polymer-based notes is a global trend. Polymer-based notes are considered a better alternative. From a hygienic standpoint, polymer notes generally absorb less moisture and organic material than paper notes, retain less organic material (nutrients), and fewer micro-organisms adhere to the surface. These observations were echoed when The BoE introduced the £5 polymer-based note in September 2016, which prompted the comment that polymer marks a groundbreaking innovation - it's safer, stronger and cleaner [17]. However, the results of our study are interesting in that they do not confirm previous observations stating that polymer notes are hygienically superior [13], [20] – [24], but found that the levels of contamination were similar on both materials. In the present study, the intriguing finding of similarity between the contamination levels, which was expected to be higher on the euro cotton- based notes, could be attributed to different factors such as the colder climate in Estonia as a Nordic country on one side, and associated with local hygiene [37], environmental sanitation levels, more contactless transaction habits as well as its considerably smaller population compared to UK on the other.

5.2.2 Other observations

In the present study, the observations that the £5 and €5 notes were less hygienic than the £10 and €10 notes may reflect the increased handling of the lower value notes. These observations are in line with studies from other countries that confirm currency papers with lower index value were found to harbor higher microbial contamination [3], [13]. More recent studies also confirm these observations [2], [39] – [40].

However, in two different studies in Iran comparing the lower denomination 500 Rial and the higher 50 000 Rial banknotes, the higher denomination notes were found to have the lowest bacterial contamination in one study [40] and the highest in another [41]. The latter researchers [41] related the difference between their results and most other reports to the fact that, in Iran, currency notes with lower denomination such as 500 Rials are not used frequently. On the contrary, the most exchanged paper notes are the higher value 50 000 Rials. Another possible explanation was that a small sample size - only 13 pieces of 500 Rials paper notes, was analyzed in their study.

Therefore, although the results of the present study indicate that the lower denomination notes were considerably less hygienic than higher denomination notes; this should not necessarily mean that a higher denomination is cleaner per se, but rather a reflection of socio- economic factors and frequency of use.

5.2.3 ATP application for banknotes – strengths and limitations

It is generally accepted that ATP allows reliable and rapid tool to replace swab and plate count [43], however correlation between Total Viable Counts (TVCs) of bacteria and RLU values is generally poor and dependent upon sample type and location. RLU values obtained in this study indicated a bacterial loading of ~ 1.3×10^4 on the £5 and €5 notes, and ~ 2.0×10^3on the £10 and €10 notes. These values equate to TVCs of bacteria on the surfaces of the notes of ~ 25 and ~ 150 cfu per cm^2 respectively (*Webber. *Pers. Comm.*) [44]; these counts of bacteria are similar to numbers of potentially pathogenic bacteria previously found on banknotes [13].

ATP bioluminescence assay is a well-established technology that offers rapid detection systems and provides objective and meaningful measurements of cleanliness in many applications. However, the main advantage of using ATP assay of the banknotes is that the technology is non-selective i.e. the RLU values obtained only indicate the hygienic status of the notes, not the groups and types of micro-organisms or the origin of other organic soiling (e.g. contamination from skin or food-stuff).

Previous determinations of hygienic quality have employed a wide range of bacterial indicators including *Escherichia coli, Bacillus cereus, Staphylococcus aureus,* and *Salmonella species* [13]; *Staphylococcus aureus,* Streptococcus *pneumonia, Helicobacter pylori*, *Escherichia coli, Corynebacterium diphtheria, Bacillus cereus* and *Acinetobacter specie*s [6]; *Staphylococcus aureus, Escherichia coli* ,Vancomycin-Resistant *Enterococci*

(VRE) [5]; and *Enterobacter agglomerans*, *Pseudomonas* spp., *Staphylococcus aureus*, *Enterobacter cloacae*, *Klebsiella pneumonia* and *E. coli* [38]. No one single organism or group can act as an indicator of the hygienic status of the banknotes – yet they all contain ATP which will yield RLU values when tested.

A recent study has concluded that ATP residuals from organic material and micro-organisms (dead or alive) are stable when dried on to surfaces [45]. In the absence of cleaning and disinfection, the relative light unit signal will not deteriorate rapidly, making ATP a good marker to monitor cleaning [or in the case of banknotes to indicate hygienic status].

5.2.4 The role of education and mass media

As far as infection control is concerned, the findings of the present study may give the meaning of the phrase "Dirty money" another dimension. Although many of the types of bacteria often identified on banknotes are merely harmless environmental bacteria which considered non-pathogenic, many are either common human pathogens or potentially pathogenic. To name but a few, *K. pneumonia* is a contagious organism and may cause both community and hospital-acquired infections (HAIs). *Escherichia coli* can cause bloody diarrhea and sometimes even deadly kidney failure. *Pseudonomnas aeruoginosa* can cause respiratory and urinary tract system infections. Antibiotic-resistant bacteria such as MRSA can also survive on banknotes and cause life-threatening blood infections. Even those organisms that are not commonly linked with disease in healthy hosts, they can potentially cause serious infections in hospitalized and immuno- compromised patients [1], [4] – [6], [14] – [15]. The implications of disease transmission between healthcare and community settings can be devastating [5] – [7], [15] – [16].

The issue of money as a potential carrier of infectious agents was highlighted as early as 1949 [46] and numerous studies from almost every country have since confirmed these observations and prompted warnings that appropriate health and safety information about microbiological contamination of currency should be disseminated [37]. However, despite accumulating data and the growing awareness of the public health risks of handling 'dirty money' little is being done to educate the public to the risks. In fact, there is a great deal of hygienic paralysis towards addressing this problem. To address this problem effectively, it is necessary to extend safety culture concepts outside the workplace and beyond legal compliance. Convincing people to change their attitudes and perceptions of the potential risks and the way they handle currency could be very difficult. After all, humans are creatures of habits. From a psychological viewpoint, according to psychologist Donna Dawson [47] this hygienic inertia could be a symptom of out of sight, out of mind. Microbes on banknotes cannot be seen by unaided eyes. And it is often difficult to relate to something that cannot be seen. For many, it is like being concerned about the microorganisms in the water we drink or in the air we breathe – we can't see them and thus we have no control over them [47].

Therefore, the role of education and mass media is essential when planning for health and safety information dissemination. National media can offer added-value presenting, discussing and analyzing relevant safety information at various levels. Essential contributions towards raising awareness and addressing the gaps in the current safety climate could be made by national press and media, as well as scientific discussion (publications, journals and web-sites) that endeavor to build and sustain a stronger safety culture [48] – [49].

5.2.5 The *'estcoin'* proposal- another dimension

The Rogoff's vision for a 'cashless society' in his book "The Curse of Cash" [50] based on economic and social arguments, would be unfeasible in the foreseeable future. For some critics, it would be even less fetching to argue for such a proposal on mere public health grounds. Nevertheless, some countries such as Sweden have already banned cash in many locations. Moreover, several countries around the world are considering launching their own digital currency as a rival to the well-known Bitcoin and Ethereum.

Estonia, on the other hand, with its e-Residency program may have an advantage in the public-sector digital infrastructure that is already very well established. Some countries may undermine other potential benefits that digital currency can provide, and merely consider it as a way of encouraging foreign investment and eventually increasing the country's economic size, yet the introduction of national cryptocurrencies may also play a key role in reducing the potential health risks associated with circulating contaminated cash.

Estonia has already proposed to launch its own state-backed cryptocurrency, called ‘Estcoin’ which could become smoothly twined with the rest of its e-Residency ecosystem. *Estcoins* could be used to pay for both public and private services in Estonia and ultimately function as attainable currency used globally [51]. Therefore, if Estonia succeeds in passing its ‘Estcoin’ initiative, it will not only affirm its position on the map as a haven for the blockchain technology and serve as a good model for how societies can be served in the future digital era, but such a step could eventually reduce the potential public health risks associated with paper notes. Notwithstanding, the ‘Estcoin’ proposal is critically considered by many as “a solution waiting for a problem” [52], the author is adamant there is enough evidence to suggest that the continuous circulation of contaminated cash, presents a justifiable concern that is pleading for a solution.

5.2.6 Other recommendations

At an individual level, in addition to encouraging ‘contact-less payment’ methods such as Google wallet, hand-washing should be maintained whenever banknotes are handled, especially when combined with simultaneous handling of food and should be made part of every meal before eating, cooking, or feeding others. Events such as the Global Handwashing Day (GHD) should be feted at schools. Hand hygiene behaviour change should be promoted in research, policy, and advocacy programs as an affordable and effective way to prevent diseases.

Another recommendation would be to create a short-term emergency platform similar to the *Adyen’s* modern infrastructure or *Click2sell* where every business and citizen can be provided with a temporary free digital wallet. Such a system should have the capacity to switch the entire nation or any city, for that matter, to digital transactions only and keep the economy functioning in case of deliberate contamination of banknotes at a massive scale.

Finally, at the institutional level, the European Central Bank (ECB), the Bureau of Engraving and Printing (BEP) in the US and all national central banks should be encouraged to include a biological hazard warning sign into the design of banknotes to warn the user of the potential health risks and raise public awareness of this global problem.

5.3 The limitations of the study

To the authors' knowledge, the present study is the first of its kind to apply the ATP assay for the assessment of the hygiene status of banknotes from two different countries. While this method served the purpose of the present study, it stops short of addressing the potential influence of the banknotes' material (polymer vs cotton) in virus transmission. The relatively small sample size (n=80) has its own limitations; the author was compelled to limit the sample size due to economic, geographic and other reasons. Furthermore, correlation between TVCs of bacteria and RLUs values is generally poor since both viable and non-viable microbial ATP is measured, a selective extraction method to separate the two could have delivered additional results ensued by a deeper insight in terms of data interpretation.

6 Summary

The main aim of the thesis was to compare the levels of potential contamination of cotton-based and polymer-based banknotes to determine the most hygienic notes using ATP [Adenosine triphosphate] assay. Sub-aims were to introduce the concept of ATP technology as a verification method for hygiene monitoring of banknotes and to present some aspects of the controversies that surround the polymer alternative.

In the present study, all tested samples were found to be contaminated (100%) recording failed ATP scores i.e. higher than 30 RLUs. The levels of contamination were similar on both materials. Hygiena systems offer no recommendations for Pass limits for banknotes. A level of 50 RLU seems reasonable, this is the value regarded as a fail in public areas of hospitals. Although ATP assay could not identify microbial species, where cases of deliberate contamination are suspected, it may offer a rapid and objective estimation of the risks.

The present study provided the first scientific evidence that ATP could be utilized for this application, and that the assay procedure was rapid and simple to use. The observation that all samples (100%) were found to be contaminated may reflect a gap in our knowledge regarding the efficacy of the current solutions. It also may pose a challenge to the advocates of the polymer banknotes and raise issues as to their hygienic supremacy.

This study can help key stakeholders, policy and decision makers in countries who are planning to shift from paper to polymer notes for hygienic reasons. In Estonia, it may donate an informed feedback on the added value of the '*estcoin*' initiative in terms of its potential hygiene benefits and a call to push forward with the proposal.

In the future, this study can be extended to further investigate the efficacy of other possible solutions and assess the reliability of ATP assay under different conditions.

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