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RESEARCH ARTICLE

Disposable diaper consumption and waste in urban Ghana and Kenya: The role of manufacturing, distribution, and branding

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Abstract

Studies have reported widespread disposable diaper (DD) consumption in parts of urban Africa, increasing municipal waste generation and with mismanaged DD waste impacting water quality. However, the DD manufacturing and distribution systems behind this trend are little studied, yet understanding these underlying systems is critical in informing efforts to promote extended producer responsibility. This study therefore aims to assess DD brand preferences and trends in international trade in absorbent hygiene products in two case study Sub-Saharan countries. A cross-sectional survey was undertaken of 440 carers of children aged 0–36 months attending health facilities in Greater Accra, Ghana and Kisumu, Kenya. Survey analysis was supplemented by analysis of international trade in absorbent hygiene products for both countries from 2000–2021. Trade data showed DD imports to Ghana and Kenya increased from 2000–17 particularly from China, but declined thereafter. This coincided with Chinese foreign direct investment establishing DD production facilities within both countries in 2018–19, and increased DD exports from Kenya and Ghana to surrounding countries. Meanwhile, 93.0% and 94.2% of survey respondents in Greater Accra and Kisumu respectively reported using DD. In Greater Accra and Kisumu respectively, 62.4% and 45.3% of survey participants reported using the brand produced by these new domestic manufacturing facilities, with 29.8% and 40.9% using imported brands. In Greater Accra, approximately half of reported imported brands were unregistered with the regulator. Given its market dominance, we therefore recommend engagement with the leading manufacturer to identify product or waste management innovations to address water pollution from DD waste. We also recommend similar engagement with imported brand manufacturers and greater DD import regulation in Ghana, given lack of imported brand registration.

Comtrade international trade data are available from https://comtradeplus.un.org/.

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Introduction

By 2030, target 11.6 of Sustainable Development Goal (SDG) 11 seeks to "reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management" [1]. Meanwhile, Target 6.2 seeks to "achieve access to adequate and equitable sanitation and hygiene for all and end open defecation" [2]. Disposable diaper (DD) consumption may affect progress towards both goals, increasing solid waste generation on the one hand, whilst providing a convenient child faeces disposal option on the other. Market research forecasts that DD sales will grow between 2022 and 2027 from 4.5 billion kg/year of DD to 5.6 billion kg/year in Asia and from 0.74 to 0.93 billion kg/year in Africa [3], with the tonnage of African DD sales approaching those in Europe by 2027. Meanwhile, a series of local studies have identified widespread DD consumption in some Sub-Saharan African (SSA) cities, with 60.7% reporting DD use in Gweru, Zimbabwe [4] and 86.2% in Nairobi County, Kenya [5]. Our recent national-scale analysis of household expenditure surveys in Ghana, Kenya and Nigeria found that approximately half of households with children of diaper-wearing age reported purchasing DD [6]. Furthermore, most DD consumption in Kenya and Nigeria occurred in households lacking adequate solid waste disposal systems. However, household expenditure surveys, such as the Ghana Living Standards Survey, have only recently introduced commodity codes for DD, so DD consumption estimates are unavailable for older household expenditure surveys [6]. Thus, unlike for packaged water consumption, which is recorded by multiple, successive population censuses and household surveys, detailed data on long-term DD consumption trends in low- and middle-income countries (LMICs) are lacking. Since market research reports typically analyse trends by world region only [3], there is a need for more granular understanding of DD production and consumption trends and their drivers at national and sub-national level.

There is evidence from high income countries of benefits from DD use, particularly for children's carers. With the emergence of community diaper banks in the USA providing free DD to low-income families, some studies in high income countries now formally define diaper need–the lack of sufficient diapers to keep a child clean, dry and healthy [7]. Free DD provision and this definition also reflect the potential time saving benefits for the mostly female children's carers and related income generation, care, and wellbeing opportunities, together with reduced carer anxiety [7–9].

Conversely, increased DD consumption presents challenges for municipal waste management, particularly in LMICs where waste collection service coverage is low [10]. There are widespread reports of mismanaged, discarded DD entering the environment throughout Africa. This threatens progress towards Sustainable Development Goal target 11.6, which seeks to reduce the per capita environmental impact of cities, particularly those relating to municipal solid waste management [11]. For example, DD were dumped at riverside sites accessible to livestock and wildlife in rural South Africa [12], whilst DD constituted a significant proportion of municipal waste streams and household waste dumps in Gweru, Zimbabwe [4]. In cities, inappropriate disposal of DD may block storm-drains and sewers [13], whilst their entry into aquatic ecosystems risks exacerbating eutrophication, reducing water quality, and ultimately contributing to micro-plastic loads [14]. Meanwhile, in Kenya, a United Nations waste hot-spotting study [15] identified DD as the fifth largest product by weight entering the environment because of mismanagement, whilst urban transect surveys in Kisumu's slums found locally high densities of discarded DD [16].

DDs are usually composed of several plastics, including polyethylene and polypropylene, cellulose and a super-absorbent polymer (SAP), which can absorb up to 300 times its weight in liquid [13, 17]. Mismanaged DD waste causes long-term environmental degradation due to

their robust polymer and SAP constituents [18], taking 250–500 years to disintegrate [19]. SAP, microplastics, and other chemicals can leach into the environment, harming soil, water, and marine life. Improper disposal of DDs containing faeces may have a long-term impact on water and soil quality, endangering humans and wildlife [12]. Discharging pathogens and chemicals from decomposing DD can disrupt ecosystems and risk biodiversity [20]. These pollutants' long-term persistence thus risk accelerating habitat deterioration.

Reflecting the trade-off between their potential benefits versus waste management impacts, policy proposals in relation to DD consumption vary markedly, ranging from free DD provision to an outright ban. In Kenya, for example, free DD have been promised during electoral campaigns [21], whilst alongside this, local county governments have called for a complete ban on DD use [22]. At international level, the United Nations Environment Programme (UNEP) has proposed five strategies to identify waste hot-spots [23], through plastic waste analyses by polymer, industrial sector, location, waste management stages, and applications. The latter "applications" or product-based perspective focuses on identifying and targeting waste management strategies at specific products contributing significantly to waste generation. One such management strategy entails Extended Producer Responsibility (EPR). These frameworks serve as critical policy tools aimed at holding manufacturers accountable for the entire lifecycle of their products [24], ensuring their involvement in waste management and disposal [25]. EPR has been proposed as a policy response to DDs [14]. However, large informal manufacturing sectors and lack of regulation, which enable producers to evade EPR costs [26, 27], impede its viability in LMICs. Although studies have characterised the scale, environmental impacts and socio-economic patterns of DD consumption, evidence is limited concerning DD manufacturing and distribution practices in LMICs particularly to assess the potential viability of EPR.

Given lack of evidence on DD manufacturing in SSA, this study firstly aims to assess the market share and segments associated with different DD brand types, including in relation to household diaper disposal. Secondly, it aims to quantify trends in international trade of absorbent hygiene products (AHPs) in two case study SSA countries, namely Ghana and Kenya. In addressing these objectives, the study seeks to inform DD-related policy responses, particularly in supporting application-based waste hot-spotting.

Methods

Study countries and cities

The study took place in two contrasting case study LMIC cities: Kisumu, Kenya, and Greater Accra, Ghana. As a capital city with a 2021 population of 5.5 million [28], Greater Accra's distribution and retail systems likely differ from those of Kisumu, Kenya's third largest city with a 2019 population of 398,000 [29], with Greater Accra acting as a distribution hub. The cities' municipal waste service coverage also differs, affecting household options for DD disposal. Waste collection services covered 68% of Greater Accra's urban households in 2021, compared to 18% of Kisumu's urban households in 2019 [30]. Finally, in terms of national waste management strategy, Kenya has implemented several waste reduction measures, notably banning plastic carrier bags [31]. In contrast, Ghana's strategy entails taxation, most recently via a Sanitation and Pollution Levy introduced on petroleum and related products including plastics in 2021, intended to promote waste management and recycling [32].

Both countries regulate DD production. In Kenya, DD manufacturing is regulated by the Kenya Bureau of Standards (KEBS) under standard KS EAS 969 [33]. Locally manufactured products must display a standardisation mark under a mandatory product certification scheme that incorporates this standard. KEBS also oversee an import standardisation mark, which is

used for imported products and incorporates product batch traceability markers. Similarly, in Ghana, DD are manufactured under Ghana Standards Authority (GSA) production specification GS 1166:2017 [34], with registered products labelled with the GSA kite mark. Imported and domestic DD should also be registered with Ghana's Food and Drugs Authority (FDA).

Survey of child faeces disposal and diaper use

Given that the quality and coverage of African trade data have been criticised [35], we undertook a survey of DD use among children's carers to enable subsequent triangulation of findings emerging from the survey and trade data. Initial market reconnaissance of retail outlets serving slums in both cities was used to identify DD brands. During this reconnaissance exercise, it became apparent that many small-scale retailers were selling defective imported DD brands that had failed quality control checks (e.g. with non-functional adhesive strips), termed 'foreign used' or 'fose' products by vendors and consumers alike in Greater Accra. Between 20th March and 21st October 2023 in Kisumu and 20th March and 27th August 2023 in Greater Accra, a cross-sectional questionnaire survey was undertaken of children's carers attending Child Welfare Clinics (CWC) at selected health facilities in both cities. Eligible participants were adults accompanying children aged 0–36 months as described in more detail for a related analysis [36]. In Kisumu, carers were surveyed in waiting rooms at four purposively selected health facilities, of which two were private and two publicly funded, with one of each pair serving a high-income population and a low to middle income population respectively. In Greater Accra, questionnaire surveys also took place at two public and two private facilities again with different catchment populations, except selection was random following stratification of facility lists from Ghana Health Services.

The sample was powered to test for differences in mean daily DD use by household socio-economic status. Based on childcare behaviours in both cities and market research data from other LMICs [37], we assumed nappy use of 4 DD/child/day among high socio-economic status households versus 2.5 DD/child/day among medium or low socio-economic status households, with a standard deviation of 2 DD/child/day. With equally sized socio-economic groups and with 90% power (alpha = 0.05), this gave a required sample size of 39 in each income group within each 12-month age cohort, rounded to 40 children. This gave a desired sample size of 240 children's carers in each city (summing across three age cohorts and two socio-economic groups).

Quota sampling was used to recruit the required number of children's carers in each 12-month age cohort and facility. Following obtaining of informed consent, survey teams asked carers about their own and child's age and gender, education, housing characteristics and economic activity. Respondents were also asked about child faeces disposal and for those using DD, their preferred DD brands, prices, purchasing transactions, and methods of DD disposal in relation to the child attending for healthcare. Surveys were conducted in local languages, namely Dholuo, Kiswahili or English in Kisumu and Twi, Ga, Ewe, or English in Greater Accra, with responses recorded on tablets using SurveyCTO software [38].

To assess whether DD brands were produced locally or imported, we compared reported DD brands preferred by Kisumu respondents with publicly accessible records of DD manufactured in-country under KEBS' standardisation mark certification scheme [39]. For Greater Accra, we compared preferred brands with publicly accessible GSA records of registered manufacturers [40]. This enabled us to differentiate imported DD brands from locally manufactured brands registered with regulators for subsequent analysis. Additionally, we requested details of foreign and domestic DD brands registered with Ghana's FDA, receiving details on 3rd May 2024, enabling us to further differentiate registered versus unregistered imported

brands in Greater Accra. We were unable to access equivalent regulatory records for imported brands in Kenya.

To characterise household socio-economic status, a simple wealth index was created following the methodology adopted in Demographic and Health Surveys [41]. The index comprised the first component from a Principal Component Analysis of a set of binary variables reflecting asset ownership (house, TV, car), services (improved water source and sanitation), being economically active (for those of working age), and having attended secondary or higher level education.

Having classified DD brands, we then used chi square analysis to assess the relationship (alpha = 0.05) between brand type, affordability as stated reason for brand preference, household wealth quintile, DD disposal mode, and reported purchases of single versus bulk DD. Waste collection services or use of a public waste dump or bin were considered adequate DD disposal modes, whilst burning, burying, or dumping (either into sanitation facilities or the environment) were considered inadequate. Linear regression was used to assess unit price variation by DD brand type, after accounting for any discounting for bulk purchases.

Trends in imported absorbent hygiene products

To quantify trends in AHPs imported to Ghana and Kenya, UN-Comtrade database records [42] were downloaded on 10th November 2023. Annual AHP imports from 2000 to 2021 were identified via Standard International Trade Classification LTS code 64295, which covers adult DD, tampons, and sanitary towels, alongside infant DD. UN-Comtrade records capture both imports recorded by Ghana or Kenya as the receiving country and exports recorded by the country of shipment. However, quantities of goods recorded can differ between the importing and exporting country (often termed bilateral asymmetry), be affected by outliers, and in some cases data from one country may be missing altogether [43]. This reflects differing national reporting capacities and standards, alongside import duties often constituting a greater financial incentive to record imports. These concerns over reporting accuracy and completeness particularly affect many SSA countries [35] where smuggling and illegal goods shipments may be particularly prevalent. We therefore used a Trade Data Quality Index (TDQI) to reconcile reports from importing and exporting countries [44]. Under this methodology, countries receive a high TDQI score if their trade statistics in a given year deviate little from those of trade partners, but a low score for higher deviations or incomplete trade reporting. Where trade figures were available from both importing and exporting country, those for the country with the greater TDQI score were retained [44]. We used "mirroring" (i.e. trade statistics from one country only) where only one country reported shipment of AHPs to Ghana or Kenya. Trade flow reconciliation was implemented in Stata [45].

Ethics statement

The study was approved by the Faculty of Environmental and Life Sciences Ethical Review Committee, University of Southampton, UK (Ref: 77654, approval date: 27 Oct 2022), by the Ethics Review Office of Jaramogi Oginga Odinga University of Science and Technology, Kenya (Ref no: ERC 34/11/22-07/03; approval date: 1st Nov 2022), and by the Institutional Review Board of the Noguchi Memorial Institute for Medical Research, University of Ghana (Ref: 003/20-21 amend. 2022; approval date: 9th Dec 2022). The study also received ethical approval from Ghana Health Services (Ref. no.GHS-ERC:022/05/23; approval date: 15th June 2023) and from the Aga Khan ethical review board (Ref: ADM/007/911, 3rd Oct 2023), an ethical review board overseeing facility-based research within a major Kenyan private healthcare provider network. To seek consent from study participants, a participant information was first

read and explained in a well-understood dialect to them through a translator and written consent was sought thereafter. The study did not include minors.

Results

Participant and brand characteristics

All caregivers of children in both cities agreed to participate in the study. However, recruiting older children in Greater Accra was challenging due to significantly fewer attending treatment compared to in Kisumu. The sampling quota for children aged 24–36 months was therefore reduced from 80 to 40 children. This led to a higher mean child age in Kisumu relative to Greater Accra (Table 1). Study participants appeared more affluent than the general population in both cities. For example, more respondents (22.5%) reported bottled water use than the 3.5% reported for urban Greater Accra households in the 2021 Ghanaian census [46], whilst more participants (89.1%) reported using piped water than the 63.8% reported via the 2019 Kenyan census [30] for urban Kisumu households. Similarly, in both Greater Accra and

Table 1. Characteristics of children and their carers participating in diaper use survey at health facilities.

Respondent and Child Characteristics	Category	Greater Accra: No. survey respondents (%)	Kisumu: No. survey respondents (%)
Respondent's relationship to the child	Mother	181(90.5)	230(95.8)
	Father	9(4.5)	4(1.7)
	Aunt	3(1.5)	3(1.3)
	Grandmother	4(2.0)	1(0.4)
	Carer	1(0.5)	2(0.8)
	Other	2(1.0)	
Economic activity	Engaged in economic activities, retired or on leave	111(56.0)	126(52.5)
Education	Attended secondary school or higher	139(69.5)	198(82.5)
Child age (months)	< 12	80(40.0)	81 (33.8)
	12–23	80(40.0)	79 (32.9)
	24–36	40(20.0)	80 (33.3)
	mean age.	14.8	17.2
Child sex	Male	104(52.0)	117(48.8)
	Female	96(48.0)	123(51.2)
Reason for healthcare attendance	Child illness	45(22.5)	90(37.5)
	Vaccination / weighing	139(69.5)	150(62.5)
	Carer illness	16(8.0)	
Main drinking-water source	Piped to dwelling/ compound	20 (10.0)	164 (68.3)
	Public tap / standpipe	2 (1.0)	50 (20.8)
	Bottled / dispenser water	45 (22.5)	15 (6.3)
	Sachet (bagged) water	132 (66.0)	-
	Other improved sources	1 (0.5)	9 (3.8)
	Unimproved sources	0	2 (0.8)
Sanitation access	W.C.	151 (75.5)	133 (55.4)
	Pit latrine	16 (8.0)	102 (42.5)
	Public toilet	33 (16.5)	5 (2.1)
Household solid waste disposal	Solid waste collected	161 (86.6)	121 (54.9)
Faeces management for attending child	Disposable diapers	186(93.0)	226(94.2)
Total respondents		200	240

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Kisumu, more respondents (86.6% and 54.9% respectively) reported waste collection services than in the 2021 and 2019 censuses at 68.0% and 18.0% respectively. Improved sanitation coverage was also higher among survey respondents relative to recent census figures. There was widespread DD use among households in both cities at 93.0% and 94.2% in Greater Accra and Kisumu respectively.

In Kisumu, 222 respondents reported using eight different DD brands, of which six were registered as locally manufactured under KEBS' standardization mark certification scheme and the KEBS EAS 969:2020 production standard. The remaining two brands were imported from foreign manufacturing sites. Following preliminary price data examination, one imported brand manufactured by a US multinational corporation was clearly marketed as a premium product, whilst a second brand manufactured in Kenya for a Chinese multinational company was preferred by 45.3% of respondents. These two brands were therefore classified separately within foreign and imported brands in subsequent analysis. Two further respondents reported using unbranded DD (hereafter classed as domestic) and one reported using an unspecified imported brand. One respondent had no specific regular DD brand and was excluded from further analysis.

In Greater Accra, 186 respondents reported using DD, of which three respondents had no brand preference and two did not know preferred brands, leaving 181 included in analysis. 14 respondents used unbranded DDs, and the remaining 167 reported using 14 different DD brands, only one of which was registered as locally manufactured with GSA, again by the same Chinese multinational as in Kenya. Preliminary analysis indicated the same brand produced by a US multinational was sold at a premium price, so this was analysed separately within imported brands. FDA records comprised 64 brands, of which 56 were foreign-manufactured. Of the 13 foreign-manufactured brands reported by survey respondents, six were registered with the FDA, so registered and unregistered foreign brands were differentiated in Ghana for analysis.

Disposable diaper brands, market segments, and consumer behaviours

When household and transaction characteristics were disaggregated by brand type in Kisumu (Table 2), the imported premium brand was significantly more expensive (mean unit price: KSh30.9, US$0.23) relative to other brands (price range: KSh19.8–22.7, US$0.16–0.18) and preferred by most households in the wealthiest quintile. Significantly fewer respondents cited affordability as their reason for purchasing this brand, compared to other domestically produced brands. There was significantly greater reported use of other domestically produced brands among the poorest households. Reflecting these trends, 'Kadogo' (meaning small in Kiswahili) purchases of single DD were significantly more prevalent for domestically produced brands, with bulk purchases less frequent. Despite significantly greater use of domestically produced DD brands among poorer households, there was however no significant association between brand type and households reporting an inadequate means of DD waste disposal.

Significantly fewer respondents (29.8%, Table 3) in Greater Accra reported using imported brands compared to Kisumu (40.9%; chi = 5.3, p = 0.02). The leading domestic brand also had a significantly greater market share in Greater Accra (62.4%) compared to Kisumu (45.3%, chi = 11.7; p = 0.001), with unbranded DD (7.7%) also significantly more prevalent than in Kisumu (0.9%, Fisher's exact test$<$0.001). The premium imported brand cost significantly more than other brands (unit price: GHS2.86, US$0.21 versus GHS1.50–1.73, US$0.11–0.13) and imported DD consumption was significantly greater among wealthier households in Greater Accra (Table 3). Affordability was also significantly more cited as a reason for purchasing unbranded DD, but variation in inadequate DD disposal by brand type was not significant.

Table 2. Household characteristics and usage patterns disaggregated by DD brand type for Kisumu.

Transaction / household characteristic[a]	Imported premium brand	Other Imported brands	Domestic leading brand	Other domestic brands	Total
Reported 'kadogo' purchase of DD sold individually *	3 (9.4%)	12 (20.0%)	37 (36.3%)	9 (29.0%)	61 (27.1%)
Purchased because of low cost *	4 (12.5%)	17 (28.3%)	28 (27.5%)	15 (48.4%)	64 (28.4%)
Mean unit price (KSh) ***	30.9	22.7	20.1	19.8	25.6
Household wealth quintile ***:					
Poorest	2 (6.3%)	13 (21.7%)	19 (18.6%)	11 (35.5%)	45 (20.0%)
Poor	2 (6.3%)	13 (21.7%)	24 (23.5%)	7 (22.6%)	46 (20.4%)
Middle	0 (0.0%)	9 (15.0%)	25 (24.5%)	8 (25.8%)	42 (18.7%)
Wealthy	6 (18.8%)	14 (23.3%)	22 (21.6%)	3 (9.7%)	45 (20.0%)
Wealthiest	22 (68.8%)	11 (18.3%)	12 (11.8%)	2 (6.5%)	47 (20.9%)
Inadequate DD waste disposal by household	9 (28.1%)	16 (26.7%)	31 (30.4%)	12 (38.7%)	68 (30.2%)
Total	32 (14.2%)	60 (26.7%)	102 (45.3%)	31 (13.8%)	225

[a] * P<0.05

** P<0.01

*** P<0.001

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In narrative survey comments, two respondents also mentioned relatives working overseas shipped DD to Ghana. Eight Kisumu respondents noted how cheaper, lower quality DD brands absorbed urine less effectively than premium brands, increasing numbers of DD used and discarded subsequently.

Table 3. Household characteristics and usage patterns disaggregated by DD brand type for Greater Accra.

Transaction / household characteristic[a]	Imported premium brand (not registered)	Imported brands registered with FDA	Imported brands not registered with FDA	Domestic leading brand	Un-branded	Total (% of respondents)
Reported 'kadogo' purchase of DD sold individually	0 (0.0%)	0 (0.0%)	1 (7.7%)	14 (12.4%)	2 (14.3%)	17 (9.4%)
Purchased because of low cost *	1 (8.3%)	3 (10.3%)	1 (7.7%)	13 (11.5%)	6 (42.9%)	24 (13.3%)
Mean unit price (GHS) **	2.86	1.90	1.38	1.55	1.50	1.69
Household wealth quintile ***:						
Poorest	0 (0%)	0 (0%)	4 (30.8%)	29 (25.7%)	1 (7.1%)	34 (18.8%)
Poor	1 (8.3%)	3 (10.3%)	2 (15.4%)	25 (22.1%)	3 (21.4%)	34 (18.8%)
Middle	2 (16.7%)	3 (10.3%)	5 (38.5%)	40 (35.4%)	6 (42.9%)	56 (30.9%)
Wealthy	5 (41.7%)	12 (41.4%)	1 (7.7%)	17 (15.0%)	3 (21.4%)	38 (21.0%)
Wealthiest	4 (33.3%)	11 (37.9%)	1 (7.7%)	2 (1.8%)	1 (7.1%)	19 (10.5%)
Inadequate DD waste disposal by household	1 (8.3%)	1 (3.5%)	0 (0%)	15 (13.3%)	2 (14.3%)	19 (10.5%)
Total	12 (6.6%)	29 (16.0%)	13 (7.2%)	113 (62.4%)	14 (7.7%)	181

[a] * P<0.05

** P<0.01

*** P<0.001

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Trends in imports of absorbent hygiene products

Among the 1567 annual records of AHP export quantities from other countries into Ghana or Kenya, most (62.5%) were reported by one trade partner only (S1 Table). For a further 35.0% of records, TDQI was greater for the exporting country rather than Ghana or Kenya, so their quantity estimates were used. Ghanaian or Kenyan estimates of AHP import quantities were used for the remainder.

When reconciled AHP imports into Ghana and Kenya are disaggregated by trade partner country (Fig 1), China dominates this trade with Ghana. Although China is also the leading partner exporting AHPs to Kenya, other countries, notably Egypt and Turkey, are also major trader partners in AHP.

Given China's dominance in AHP trade with Ghana and Kenya, trends in AHP exports from China and Hong Kong are presented separately in Fig 2. There was rapid growth in AHP trade from China and Hong Kong to Ghana from 2011 onwards (Fig 2A). However, from 2019 onwards, this trade rapidly declined. Despite this drop in Chinese trade, trade in AHP from other countries to Ghana continued to follow a long-term growth trend beyond this year. In Kenya (Fig 2B), again there was rapid growth in Chinese AHP from 2014 onwards, but this international trade rapidly declined from 2019 onwards. As with Ghana, AHP exports from other countries to Kenya have steadily increased since 2000, including after 2019. In both countries, the same broad trends are apparent, regardless of whether Ghanaian and Kenyan import statistics, partner countries' export statistics, or reconciled trade data are used.

Meanwhile, reconciled UN-Comtrade data showed that exports of AHPs into Côte d'Ivoire and Senegal rapidly increased from 2019 in Ghana (Fig 3A) and into Uganda and Tanzania from 2020 in Kenya (Fig 3B).

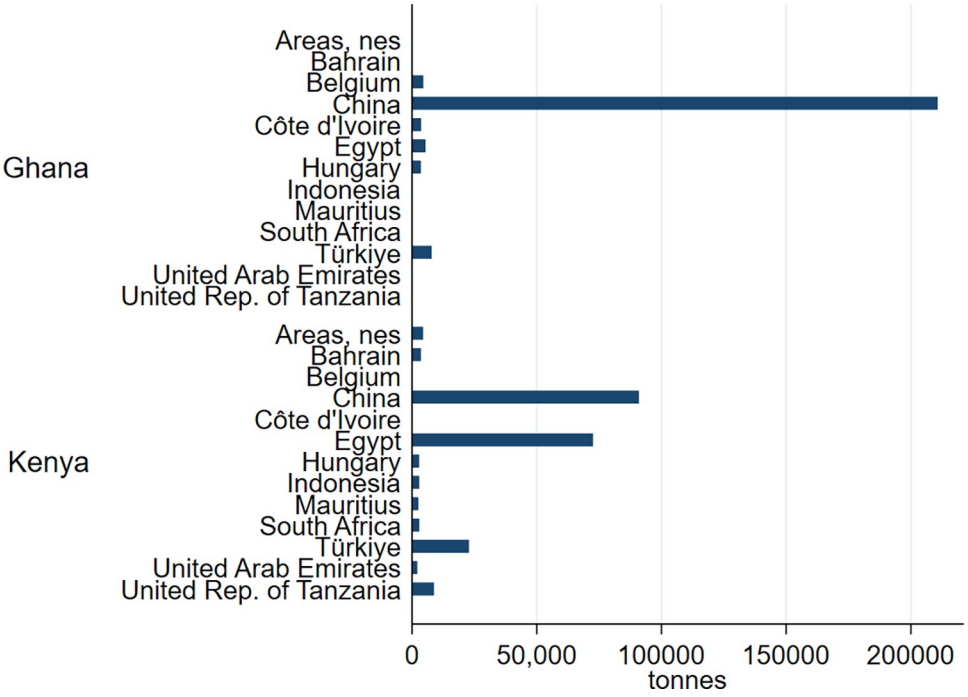

Fig 1. Tonnes of absorbent hygiene products exported to Ghana and Kenya by country of export, 2000–21. Only countries exporting more than 2,000 tonnes of diapers shown; Areas nes, not elsewhere specified indicates trade partner identity data were missing.

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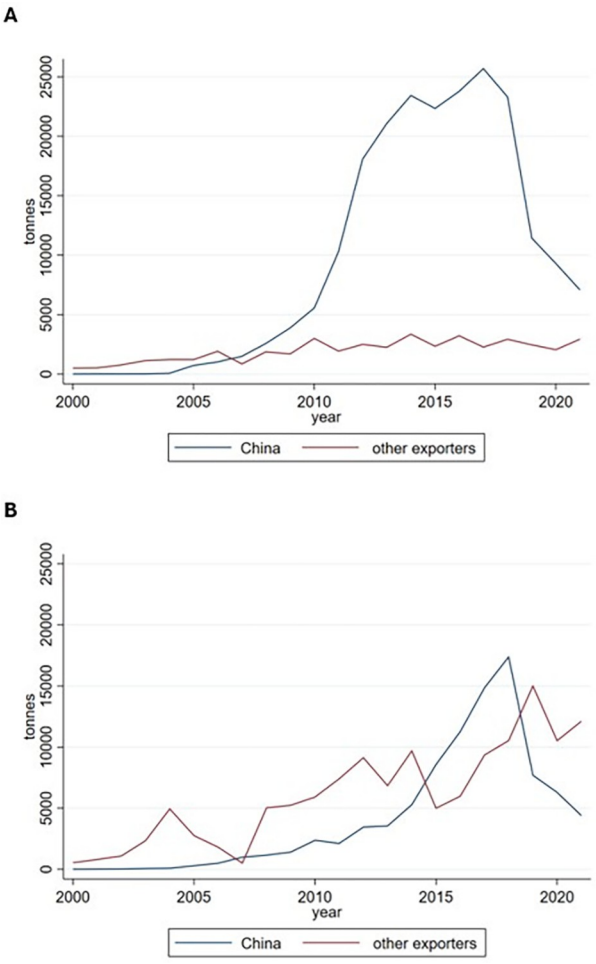

Fig 2. Annual tonnes of absorbent hygienic products imported from China and Hong Kong versus elsewhere, 2000–21. (A) For Ghana. (B) For Kenya (source: UN-Comtrade).

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Discussion

The decline in AHP exports from China to Ghana (Fig 2) seems surprising, given widespread consumption of DD among our sample of children's carers in Greater Accra. However, in December 2018, a US$40 million baby diaper production plant operated by a Chinese multinational company, described as one of the largest in SSA, was commissioned in Accra [47]. The same company opened a US$39 million diaper production plant southwest of Nairobi in the following year in a Special Economic Zone [48], capable of producing 350 to 450 million DD to meet an estimated nationwide demand of 800 million DD [49]. This company also produced the most frequently used brand reported by 62.4% and 45.3% of our survey respondents in Greater Accra and Kisumu respectively (Tables 2 and 3). Thus, both our DD use survey and the changing AHP import pattern in UN-Comtrade data highlight a strategy on the part of Chinese manufacturers to produce DD in Africa, rather than exporting DD from factories in China. UN-Comtrade data show that both Ghana and Kenya subsequently rapidly became regional DD manufacturing hubs, exporting DD to surrounding countries from 2019 onwards (Fig 3). This shift in DD production from China into Africa reportedly reduces production costs by 20% to 30% and thereby reduces prices [49], thus making DD affordable to more

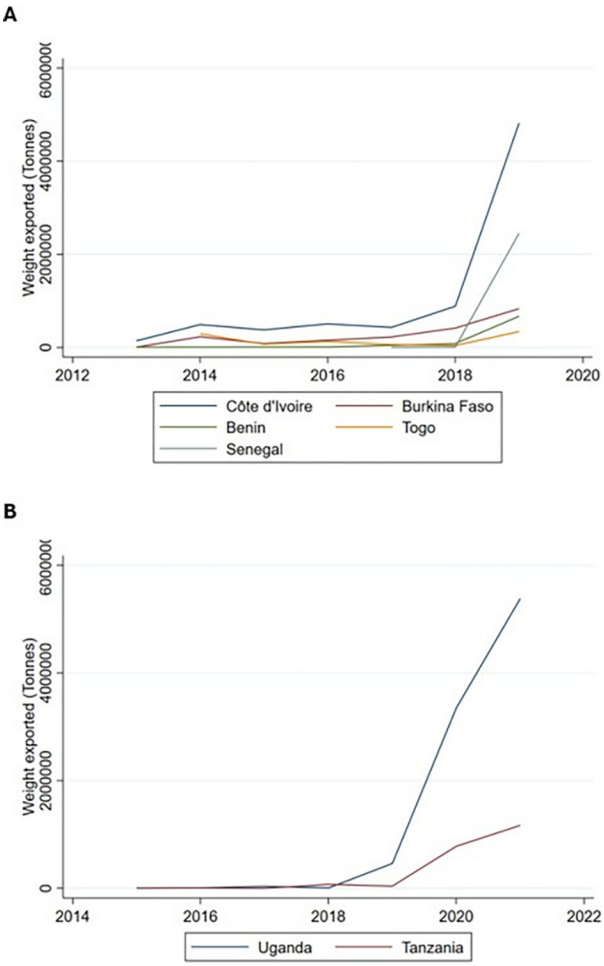

Fig 3. Tonnes of absorbent hygienic products exported annually from 2012 to 2021. (A) from Ghana into selected neighbouring countries (B) Kenya into selected neighbouring countries (source: UN-Comtrade).

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consumers. Simultaneously, retailers break out DD bags and sell diapers individually (Table 2), thereby enabling poorer households with limited cashflow to smooth DD consumption via smaller, more frequent 'Kadogo' purchases [50]. Thus, DD growth among the poor reflects both their changing manufacturing and distribution, the latter in the form of 'kadogo ('small') economy' purchases. The latter Swahili phrase refers to small-scale transactions by poorer households [51], which we also observed for DD purchased and reported in national household expenditure surveys [6].

Impact evaluations of China's Belt and Road initiative (BRI) have typically focussed on the immediate environmental impacts of infrastructure construction [52, 53], as opposed to associated foreign direct investment in manufacturing such as Special Economic Zones. Assessment of its socio-economic and poverty reduction impacts have focussed on employment generation and trade cost reductions following infrastructure improvements [54]. Our study highlights less proximate, secondary environmental impacts linked to the BRI, namely increased mismanaged DD waste as DD become affordable to urban populations lacking waste services. There may also be secondary socio-economic benefits, given that US studies evaluating free DD provision via diaper banks highlight their time-saving and other benefits for mothers [8, 9].

Several Kisumu respondents noted that lower quality, cheaper brands were less effective at absorbing urine. Given that DD contain a super-absorbent polymer to contain urine [55], it seems likely that some budget DD manufacturers may be reducing costs by decreasing polymer quantities in their products.

This widespread DD consumption appears to form part of a wider trend towards commodification of water, sanitation and hygiene (WASH). The WHO/UNICEF Joint Monitoring Programme have highlighted global growth in packaged water (water sold in plastic bottles or bags, the latter termed 'sachet' water in West Africa) consumption. Over 20 million people in the 10 most populous countries with available data reported packaged water as their main source in 2015 [56]. More recent surveys from 2016–2020 have reported packaged water use by 50% or more of urban households in Ghana, Lao, the Philippines, and Indonesia [57] and approaching 50% in Nigeria. However, although both packaged water and DD consumption are increasing in LMICs, our study suggests their production patterns differ. We previously compared sachet water brands with regulatory database records via market surveillance in Greater Accra [58], finding a wide range of brands on sale. Of these, 65% of sachets sampled had matching regulatory records. Thus, a substantial proportion of sachet brands on sale were unregulated, with sachet production overwhelmingly domestic, sometimes under franchise from leading brands and often close to consumers given the high costs of transporting packaged water as a bulky commodity [58]. In contrast to sachets, far fewer DD brands were reported by our participants. Virtually all DD brands reported by Greater Accra respondents were either manufactured locally by a single multinational producer that was registered with GSA or imported (Table 3). Over half of imported brands were not registered with the FDA as regulator, suggesting that unregulated DD import, via informal resellers, family networks or smuggling is prevalent. This is confirmed by the FDA and GSA who warned of illegal DD imports smuggled in clothing bales [59]. Reported DD brands in Kisumu were similarly virtually all either imported or produced by domestic manufacturers registered with the regulator, though we were unable to obtain regulatory registration details for imported brands there. Thus, whilst the challenge for sachet water EPR to address plastic waste is the many small-scale unregistered producers, the challenge for DD–at least in Ghana–is unregulated import of DD foreign brands.

Combined evidence from the children's carers survey and the UN-Comtrade database shows how a multinational has come to dominate the DD sector in Ghana, Kenya and likely in the surrounding region also. Various studies [16, 60] have reported DD entering the SSA environment and aquatic ecosystems as mismanaged waste. One study [15] identified DD as the fifth largest product by weight in Kenyan mismanaged waste. One potential solution to this issue is to engage with manufacturers via EPR to accelerate redesign of DD products to facilitate their separation and energy recovery or support waste collectors and management systems to handle DD waste. Given the dominance of one multinational manufacturer in both Ghana and Kenya's DD market, its inclusion within industry engagement efforts seems essential if such EPR initiatives are to succeed.

The export of 'foreign used' or 'fose' goods from high income countries to Africa is well established. Examples of such goods include used clothing (sometimes termed 'obroni wawu' in Ghanaian Twi or 'mitumba' in Kenyan Kiswahili), recently banned in Rwanda [61] and second-hand cars [62]. The term sometimes encompasses not only second-hand or used goods, but also defective products that fail quality control checks. The reconnaissance phase of our survey suggests that multinational manufacturers also export 'fose' (more correctly termed defective) DD to Africa, where municipal waste service coverage is low [10]. Ghanaian media [63] have similarly reported consumption of 'fose' DD and menstrual hygiene products. This

highlights a need for greater corporate social responsibility on the part of these manufacturers too.

Examples of technologies that could reduce DD environmental impacts through manufacturer engagement are product redesign as 'glueless' diapers, which replace the glue binding DD components with innovative bonding technologies and an optimised absorbent core [64], significantly reducing their eutrophication and aquatic ecotoxicity potential. DD biodegradation by micro-organisms and pyrolysis—thermal decomposition under anaerobic, elevated temperature conditions–both also have potential as disposal technologies with lower environmental impacts [65]. However, given the informal waste collectors operating in many LMIC waste management systems, there is a need to widen waste management solutions beyond technologies to consider socio-economic waste management systems components [66], particularly DD waste valorisation [67] to incentivise its collection and management by informal collectors.

Our findings are subject to several uncertainties and limitations. The quality of the SSA UN-Comtrade data that underpin our analysis have long been questioned because of smuggling, corruption and lack of robust record-keeping [35]. More recent analyses [44] suggest SSA UN-Comtrade data deviate more from those of reporting partners globally than those for other world regions and thus are less reliable. Furthermore, in 2023, the GSA and FDA issued a joint press release [59], warning of unregistered diaper imports, often hidden in bales of used clothing or otherwise transported unhygienically. Several survey respondents also reported receiving consignments of imported DD from overseas relatives, which would also not be captured via UN-Comtrade data systems. Standard International Trade Classification commodity codes are also insufficiently granular to differentiate infant DDs from other AHPs. Our survey may underestimate mismanaged DD waste, since interviews took place in a public setting and may be subject to social desirability bias [68]. Our respondents may have over-reported more desirable, premium DD brands for the same reason. Survey respondents were also of higher socio-economic status than the two cities' general populations, so our study may over-estimate DD consumption by under-representing poorer households. Furthermore, our brand classification is dependent on the accuracy of GSA and KEBS regulatory databases, and we were unable to discriminate counterfeit brands from our data.

Although UN-Comtrade data have been used to quantify the growth in primary 'raw' plastic polymers imported to Africa [69], they have not been used to audit trade in secondary plastics, i.e. products within which plastics constitute a significant component. Our manuscript illustrates the potential to target UN-Comtrade data analysis at a specific product identified as particularly mismanaged via UNEP's waste hot-spotting approach, in this case DD [15]. There is thus potential for future studies to target international trade analyses at other products identified as major mismanaged plastic waste contributors via national waste hot-spotting initiatives. There would also be scope to expand our analysis of international AHP trade beyond Ghana and Kenya to examine global DD manufacturing patterns.

Conclusion

Our study confirms very widespread DD use in two case study African cities, where over 90% of children's carers are using DD. With consumption extending into the poorest households who lack waste collection or disposal facilities, a significant minority are unable to safely dispose of used DD. Our study also provides evidence concerning the changing manufacturing and distribution of DD in two case study SSA countries. In both Greater Accra and Kisumu, a leading brand domestically produced by a multinational dominates the market, used by 65% and 45% of children's carers respectively. Imported DD brands were also prevalent in both

cities' surveys, with some anecdotal evidence of defective DD batches being exported to these consumers. Meanwhile, international trade data illustrate how the relocation of DD manufacturing to countries in SSA from China is likely to have accelerated product consumption in the region by lowering manufacturing and distribution costs and ultimately DD retail prices. This constitutes a more distal impact of the BRI, seldom captured in assessments of its benefits or environmental impacts.

Given these findings, we recommend engagement with the multinational companies who export DD to SSA or manufacture DD within the region, so as to address the waste management and environmental impacts of their consumption, given the region's low waste service coverage. There are potentially promising emerging technologies such as glueless diapers or disposal via biodegradation or pyrolysis, whose uptake could be prioritised within this region. However, any such technologies would need to be embedded within informal waste service provider operations, who often play a pivotal role in SSA's waste management systems.

Supporting information

S1 Table. UN-Comtrade record summary for international trade in absorbent hygiene products into Ghana and Kenya, 2000–21. TDQI: trade data quality index.
(XLSX)

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