1. Introduction

The idea for this study came from a question in a chemistry lesson on galvanic cells: what happens to a battery after the toy stops working? Almost every pupil answered the same way: it goes into the bin. A battery is small, so the habit seems harmless. The problem appears only when the same habit is repeated in hundreds of thousands of households every week.

Globally, electronic waste is the fastest-growing waste stream. The Global E-waste Monitor 2024 reports a record 62 million tonnes of e-waste generated in 2022, of which only 22% was formally collected and recycled [1]. The Monitor defines e-waste as any discarded product with a plug or a battery, which includes toys and small household devices. In Uzbekistan, according to the Ministry of Ecology, about 76 t of single-use batteries are imported every year, while there is still no enterprise in the country that recycles or safely disposes of them [2]. A volunteer project launched in 2025 placed about 100 collection containers in Tashkent and the regions, but the collected batteries are only stored until a recycling route becomes available [3].

The aims of this work are: (1) to summarise, from published laboratory studies, what a common battery contains and what happens to it in a landfill; (2) to estimate the number and mass of batteries discarded in Bukhara region, from the level of a single school up to the whole region; and (3) to propose a practical collection model that schools can start without new legislation or large budgets.

2. Literature review

2.1. What is inside a battery

Household batteries are not one product. Alkaline zinc–manganese dioxide cells (AA, AAA) dominate clocks, remote controls and toys; zinc–carbon cells are their cheaper predecessors; button cells power watches and scales; nickel–cadmium and lithium-ion cells are rechargeable; lead–acid accumulators are used in cars (Table 1). Each type carries a different set of metals [4, 5].

Table 1. Main types of batteries found in households and their key components [4–7]

Battery type	Typical use	Main components	Metals of concern
Alkaline Zn–MnO_2 (AA, AAA)	Clocks, remotes, toys	Zn anode, MnO_2 cathode, KOH electrolyte, steel case	Zn, Mn; traces of Pb, Cd, Hg
Zinc–carbon	Cheap toys, flashlights	Zn can, MnO_2, $NH_4Cl/ZnCl_2$ electrolyte	Zn, Mn; Pb, Cd in older cells
Button cells	Watches, scales, calculators	Ag_2O, Zn or Li; older types HgO	Ag, Zn; Hg (now ≤2% in permitted types)
Nickel–cadmium	Older rechargeable toys, tools	Cd anode, NiOOH cathode, KOH	Cd, Ni
Lithium-ion	Phones, tablets, RC toys	Graphite anode, Li metal-oxide cathode, organic electrolyte	Co, Ni, Mn, Li; fire risk
Lead–acid	Cars, scooters	Pb/PbO_2 plates, H_2SO_4 electrolyte	Pb, sulfuric acid

The most detailed composition data for the batteries that dominate our homes come from a study of spent AA alkaline batteries by Almeida et al. [4]. An average battery weighed 23.5 g. The dry manganese dioxide cathode accounted for about half of the mass (11.9 g), the steel parts for 4.68 g, the zinc anode (metallic zinc, zinc oxide and electrolyte) for 3.86 g, and moisture for about 2 g; the potassium hydroxide electrolyte, about 0.9 g, is distributed between the anode, cathode and separator. Expressed per battery, the cathode contained about 5.4 g of manganese. The same study measured trace metals: 1.2 mg of lead, 0.060 mg of cadmium and 0.0038 mg of mercury per battery (Figure 1, Table 2).

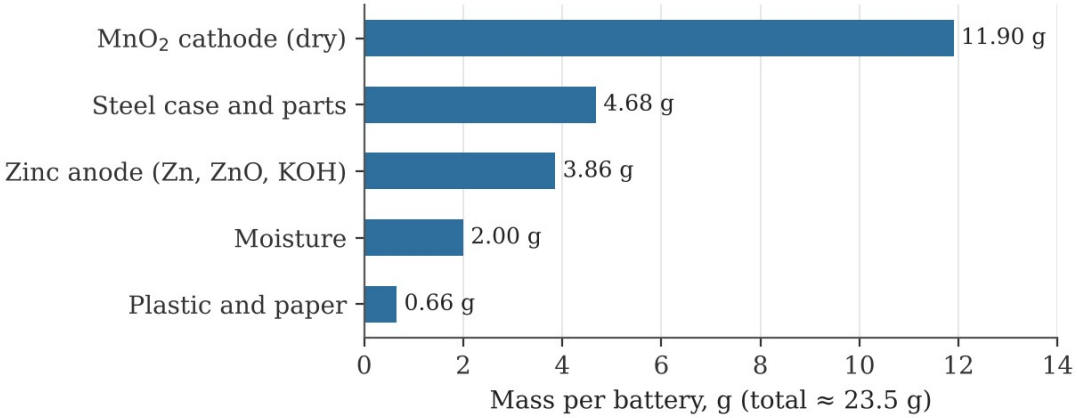

Figure 1. Mass of the main components of one spent AA alkaline battery, g (data: Almeida et al. [4]); the KOH electrolyte (~0.9 g) is contained within the anode, cathode and separator

These numbers explain why the electrolyte deserves attention. In alkaline cells it is not an acid but a strong alkali, potassium hydroxide; acids are found in zinc–carbon cells (ammonium and zinc chloride) and, in large amounts, in lead–acid accumulators (sulfuric acid). The trace levels of mercury and cadmium in modern alkaline cells are the result of regulation. The EU Batteries Directive limited portable batteries to 0.0005% mercury and 0.002% cadmium by weight and required marking above 0.004% lead [6], and the Minamata Convention on Mercury phased out mercury-added batteries from 2020, except button zinc–silver oxide and zinc–air cells with less than 2% mercury [7]. Older batteries kept in drawers and cheap unbranded cells may not meet these limits.

2.2. What happens to a battery in a landfill

A steel case does not last forever. In a landfill the battery is surrounded by rainwater and by acidic leachate produced by decaying organic waste. Karnchanawong and Limpiteeprakan evaluated, under simulated landfill conditions, how heavy metals leach from spent household batteries disposed of together with municipal solid waste [8]. In column leaching tests on spent alkaline batteries, Xará et al. found that zinc and sulphates were the substances released in the largest amounts, that cut (damaged) batteries released more

than whole ones, and that mercury was the only metal dissolved in a significant proportion of its content in the battery [9]. Incineration is not a solution either: when AA alkaline batteries were burned, metals including zinc, cadmium, lead and mercury were found in the emissions [10]. The overall pathway is summarised in Figure 2.

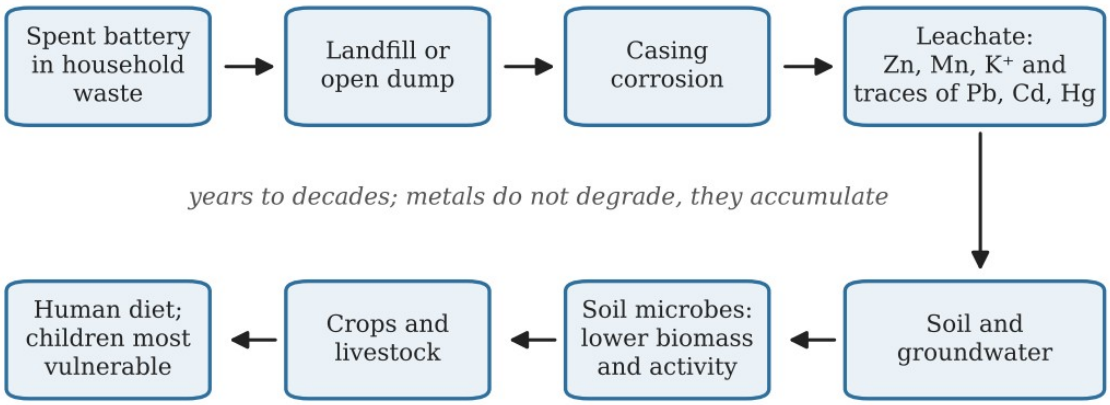

Figure 2. Pathway of battery metals from household waste to soil, the food chain and people (compiled from [8–12])

A frequently repeated statement on the internet says that “one battery pollutes 20 m^2 of soil”. We could not find a scientific source for this number and do not use it. The real issue is accumulation: metals do not decompose, so every battery adds to the stock already in the landfill and in the surrounding soil.

2.3. Soil microorganisms and the food chain

Fertile soil is a living system. Bacteria and fungi decompose plant residues, release nutrients and convert nitrogen into forms that plants can use. In a classic review, Giller, Witter and McGrath showed that heavy metals such as cadmium, copper, zinc and lead reduce microbial biomass and activity and can disturb key processes such as nitrogen fixation and organic matter decomposition [11]. Zinc and manganese are essential micronutrients at low concentrations, but they become toxic when they accumulate locally, which is exactly what happens around a dump.

Metals that reach soil and groundwater can be taken up by crops and pass into the food chain. Lead is the most serious concern for children. The World Health Organization states that there is no level of exposure to lead known to be without harmful effects, and that lead can permanently affect children’s brain development, lowering intelligence and school performance [12].

2.4. Recycling practice in the world and in the region

Batteries can be recycled: zinc, manganese and steel from alkaline cells can be recovered by pyrometallurgical and hydrometallurgical routes [5], and lead–acid batteries are among the most recycled products in the world. The limiting factor is not chemistry but collection. The new EU Batteries Regulation

sets collection targets for portable batteries of 63% by the end of 2027 and 73% by the end of 2030 [13]. In Russia, more than 450 t of used batteries were collected and recycled in 2019, yet officials estimated that only 1.7% of sold batteries were disposed of correctly [14].

In Uzbekistan, the Jizzakh accumulator plant produces batteries, but there is no established system for collecting single-use household batteries [2]. The 2025 volunteer project created about 100 containers, 72 of them in Tashkent and 28 in the regions, mostly in Ministry offices, supermarkets and educational institutions [3]. A utilization fee on traction batteries of electric vehicles was proposed for 2025 [15]; a similar extended producer responsibility (EPR) payment for portable batteries would create a stable source of funding for collection.

Lithium-ion batteries add a safety problem. The US Environmental Protection Agency identified 245 fires at 64 waste facilities between 2013 and 2020 that were caused, or likely caused, by lithium batteries thrown into ordinary waste [16]. Separate collection therefore protects not only soil but also people working with waste.

2.5. Schools as collection points

Schools have three advantages: every family is connected to one, pupils can be motivated, and the topic fits naturally into chemistry, biology and geography lessons. In Turkey, after teachers were trained to run four lessons on waste batteries, 575 fifth-grade pupils showed clearly better knowledge of what batteries contain, where to dispose of them and why recycling matters [17]. In Wales (UK), a school competition run since 2012 ranks schools by kilograms of batteries per pupil; in eight months pupils collected more than 3.3 t, diverting around 132 000 batteries from landfill [18]. These examples show that a competition element works, and that results should be measured per pupil so that small and large schools compete fairly.

3. Materials and methods

The study combines published composition data with official statistics (Table 2). Pupil numbers for the two schools named in this paper were provided by the authors; regional numbers were taken from the National Statistics Committee as reported in the press.

Table 2. Input data used in the estimate

Parameter	Value	Source
Pupils, Presidential School in Bukhara	≈330	School data (authors)
Pupils, School No. 13, Bukhara city	≈2 500	School data (authors)
General secondary schools, Bukhara region (2025/2026)	596	[19]
Pupils, Bukhara region (2025/2026)	348 400	[20]
Population, Bukhara region / Uzbekistan (1 Oct 2026)	2 125 129 / 39 535 225	[21]
Average household size, Uzbekistan	5.2 persons	[22]

Parameter	Value	Source
Mass of one AA alkaline battery	23.5 g	[4]
Single-use batteries imported into Uzbekistan	≈76 t/year	[2]
Portable batteries sold in Europe (2017)	≈226 000 t/year	[2]

Assumptions. (1) A family uses on average two batteries per week, i.e. 104 batteries or about 2.44 kg per year. (2) Each pupil represents one family. This counts families with several pupils more than once but leaves out families without school-age children; a household-based check is given in Section 4. (3) All batteries are treated as AA alkaline cells with the composition reported in [4]. AAA cells are lighter and button cells much lighter, while zinc–carbon cells may contain more lead and cadmium, so the metal estimates are indicative rather than exact.

Calculation. For a group of N pupils, the weekly number of batteries is $N_w = 2N$, the annual number is $N_y = 52 \cdot N_w$, and the annual mass is $M = N_y \cdot m$, where $m = 23.5$ g. The mass of component i is $M_i = N_y \cdot c_i$, where c_i is the content of that component per battery (Table 3).

Scenarios. Scenario H uses the assumptions above. Scenario E applies the European per-capita sales benchmark (226 000 t for about 512 million inhabitants, i.e. ≈0.44 kg or ≈19 AA cells per person per year) to the whole population of the region. Scenario L takes the region's population share of the official national import figure (76 t/year). All results can be reproduced from Table 2 and the formulas above.

4. Results

4.1. Batteries discarded at school level

Table 3 shows how quickly the numbers grow. The families of one average school in the region (585 pupils) discard almost 1 200 batteries a week, more than 60 000 a year, which weighs about 1.4 t. For School No. 13, with about 2 500 pupils, the figure reaches 5 000 batteries a week and over 6 t a year.

Table 3. Estimated number and mass of batteries discarded by pupils' families (scenario H)

Group	Pupils	Batteries per week	Batteries per year	Mass, t/year	Lead, g/year
Presidential School in Bukhara	≈330	660	34 320	0.81	41
Average school, Bukhara region	585	1 169	60 794	1.43	73
School No. 13, Bukhara city	≈2 500	5 000	260 000	6.11	312
All schools, Bukhara region	348 400	696 800	36 233 600	851.5	43 480

4.2. Regional metal load

At the regional level, scenario H gives 36.2 million batteries, or about 851 t, every year. Multiplying by the per-battery composition (Table 4) shows that this waste carries roughly 194 t of manganese and 140 t of zinc anode material, plus 33 t of caustic potassium hydroxide. The amounts of lead, cadmium and mercury are small in comparison, about 43 kg, 2.2 kg and 140 g, but these are the most toxic components and they are released into the same places year after year.

Table 4. Annual mass of battery components discarded in Bukhara region (scenario H, 36.2 million AA alkaline cells)

Component	Content per battery [4]	Annual mass in the region
Manganese (in MnO_2 cathode)	≈5.36 g	≈194 t
Steel (case and parts)	4.68 g	≈170 t
Zinc anode material (Zn, ZnO, KOH)	3.86 g	≈140 t
Potassium hydroxide (electrolyte)	≈0.9 g	≈33 t
Lead (Pb)	1.2 mg	≈43 kg
Cadmium (Cd)	0.060 mg	≈2.2 kg
Mercury (Hg)	0.0038 mg	≈0.14 kg

4.3. Comparison of scenarios

Figure 3 compares the three scenarios. Scenarios H and E are close: 851 t and 937 t per year. A household-based version of scenario H (408 700 households with two batteries per week) gives about 999 t. The European benchmark corresponds to about 1.9 batteries per household per week, which means that the assumption of two batteries per family is realistic. In contrast, the official import figure gives only about 4.1 t for the region, about 208 times less than scenario H.

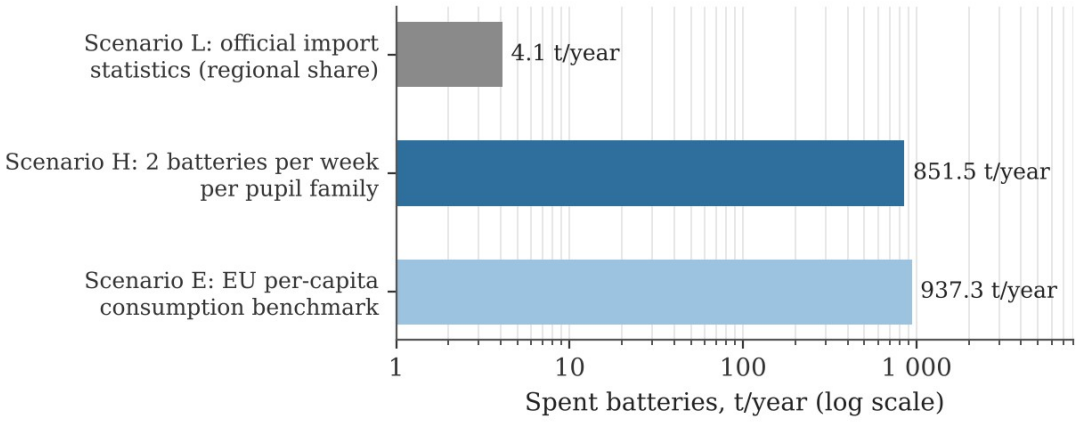

Figure 3. Annual mass of spent portable batteries in Bukhara region under three scenarios (log scale)

5. Discussion

Why the official figure is so low. It is unlikely that families in Bukhara use 200 times fewer batteries than families in Europe. More plausible

explanations are that many batteries enter the country inside devices and toys, that a part of the trade is not recorded as battery imports, and that the 76 t figure covers only some customs categories. Whatever the reason, the comparison shows that collection planning should not rely on import data alone. A simple measurement, weighing what one school actually collects over a term, would quickly show which scenario is closer to reality.

Uncertainty. The estimate is sensitive to battery size and chemistry. If half of the cells were AAA (about half the mass of AA), the total mass would fall by roughly a quarter, while a high share of cheap zinc–carbon cells would increase the lead and cadmium figures. Even under conservative assumptions, however, the result remains in the range of hundreds of tonnes per year for one region.

The school “Eco-Fund” model. Because no recycling plant exists yet, the first realistic step is to separate batteries from household waste and keep them in a controlled place. We propose an eight-step cycle (Figure 4). A closed plastic box is placed at the school entrance; each class weighs its batteries and records them in a logbook; the batteries are handed over to a licensed operator or an existing collection network [3]. Money is not expected to come from the alkaline batteries themselves: their scrap value is low and in many countries recycling them costs money. The Eco-Fund is therefore built from several sources (Table 5). It pays for school tournaments, such as chess, a chemistry quiz and sports, and for prizes, including an “Eco-Cup” for the class with the most kilograms per pupil, following the Welsh example [18].

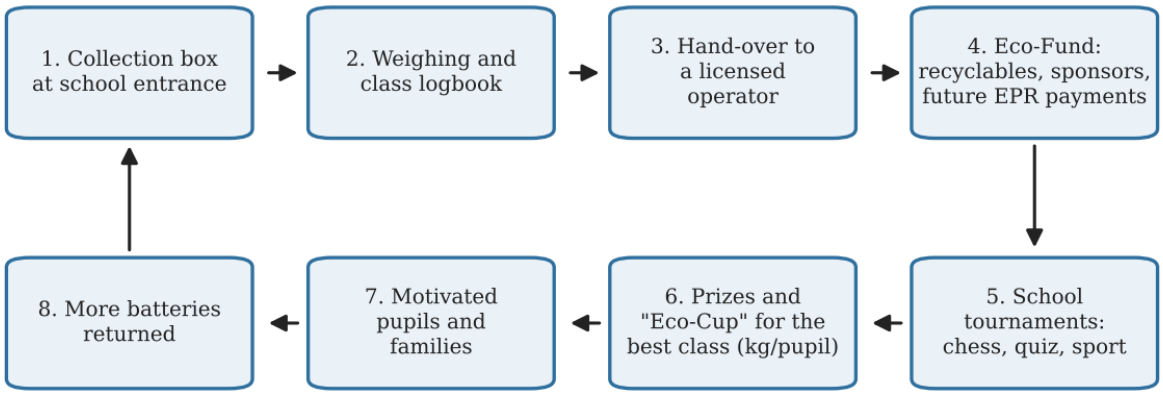

Figure 4. The school “Eco-Fund” collection cycle

Table 5. Possible sources of the school Eco-Fund

Source	How it works	Expected scale
Valuable recyclables	Old phone batteries (Co, Ni), lead–acid batteries brought by parents, waste paper and PET bottles collected in the same campaign	Main regular income
Sponsors and partners	Shops selling batteries, supermarkets with collection points, mahalla and parents’ committee	Prizes and equipment

Source	How it works	Expected scale
Future EPR payments	If a utilization fee for portable batteries is introduced, schools can be paid as registered collection points [15]	Long-term, stable
Grants	Youth ecological projects and contests of the Ministry of Ecology [3]	Start-up costs

Safety rules. A collection box must not create a new hazard. The box should be made of plastic, not metal, and kept dry and away from heat and sunlight. The terminals of lithium and button cells should be covered with tape to prevent short circuits, which can cause fires [16]. Swollen or leaking batteries are handled only with gloves and placed in a separate bag. Car batteries are not accepted at school; parents are directed to specialised collection points.

Educational value. The logbook data can be used directly in lessons: calculating mass and metal content in mathematics and chemistry, discussing soil ecosystems in biology, and mapping collection points in geography. Studies show that such hands-on activities improve pupils' knowledge and attitudes towards waste batteries [17].

Limitations. This study is an estimate based on published composition data, official statistics and an assumed consumption rate. We did not measure metal concentrations in soil near landfills in Bukhara region, and the actual consumption of batteries by families was not surveyed. These are natural next steps: a questionnaire for families and a one-term collection trial in the authors' schools.

6. Conclusions

1. A spent AA alkaline battery is not inert waste. Each one contains about 5.4 g of manganese, almost 4 g of zinc anode material, about 0.9 g of caustic potassium hydroxide and small but toxic amounts of lead, cadmium and mercury, all of which can be released in a landfill.

2. The families of pupils in Bukhara region are estimated to discard about 36 million batteries, or roughly 850 t, per year, containing about 194 t of manganese, 140 t of zinc anode material and 43 kg of lead. A European benchmark gives a similar result, while official import data underestimate the flow by about two orders of magnitude.

3. Since Uzbekistan has no battery recycling plant yet, separate collection is the most urgent step. Schools are the cheapest and most effective collection points, because they reach almost every family and can turn collection into a competition.

4. The proposed "Eco-Fund" model links collection to school tournaments and prizes, financed by valuable recyclables, sponsors and, in the future, producer responsibility payments. We recommend testing it first in the

Presidential School in Bukhara and School No. 13, and then extending it to all 596 schools of the region.

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