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Sustainable Market-Driven Strategy for Fluoride Treatment: A Case Study of Business Model Approach in Pakistan

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ABSTRACT

Purpose: The study intends to examine the sustainability of different fluoride-treatment systems through a business model approach in a developing country to achieve financial and operational viability.

Methods: We used business-model-logic to evaluate different fluoride reduction technologies to assess the financial viability of safe water supply services. We examined the investment cost involved in the de-fluoridation of water, the annual revenue generation, and the net-benefits of these different de-fluoridation technologies through business model logic. Data collection was done through field surveys and discussions with relevant stakeholders.

Results: The analysis identifies the financial viability of providing safe water services using different technologies and found that the EDF and CAB based fluoride removal techniques are better regarding cost savings and profitability. Additionally, the study highlights the potential to reduce medical expenses and productivity losses by ensuring access to fluoride-safe water, estimating yearly cost savings of $78 per person.

Conclusions: The study confirms that the business model is an effective tool for the evaluation of different technologies promoting safe drinking water solutions in a developing country like Pakistan

Key-words: Business models, economic and technological sustainability, chemically activated cow bone, Nalgonda, electrolytic delfuoridation fluoride

INTRODUCTION

Around the globe, the demand for finding and providing sustainable solutions for basic human needs, such as safe drinking water, is at an all-time high. As the demand for basic human needs such as safe drinking water increases, it is becoming more evident that entities such as government, non-governmental organizations (NGOs), and foreign aid agencies cannot meet such mounting demands. Finding sustainable solutions is linked with business models that help create sustainable practices and encourage critical suppliers to reach end users[1,2]. A business model is defined as a plan or framework of interdependent activities outlining a company strategy for creating, delivering, and capturing value through operational processes, ensuring the company runs efficiently and profitably[3,4], according to Kubli et al.[5] Innovative business models can address problems in sustainable energy. Well-designed and well-executed business models can solve major global issues, including sustainable development[6].

This paper examines the sustainable supply of safe-drinking-water in a developing country like Pakistan. According to estimates, about 260 million people worldwide drink water with fluoride concentrations above the 0.5–1.5 mg/L World Health Organization (WHO) recommended level[7]. Targeting this issue, we aim to demonstrate how business models can create sustainable de-fluoridation solutions. More precisely, we selected the fluoridated areas of the Thar desert and Quetta valley of Pakistan as test subjects to see if this approach can work in a developing country like Pakistan.

We used the business model as a tool to set up an expansion of sustainable, market-oriented fluoride removal systems, which enable safe drinking water to be common rather than an exception in these areas. Our goals are:

1. The extension of business models for social needs where sustainability and market orientation are needed and essential; we mainly focus on the safe-drinking-water problem.

2. To highlight the significance and viability of business models in examining alternatives for business activity, particularly for fluoride removal setups and systems.

3. To highlight the viability of de-fluoridation treatment technology and systems as a business scheme

Using the business model methodology, we illustrate how to compare and evaluate the sustainability of different de-fluoridation treatments regarding profitability and market orientation. By showing the business model logic with its components, we can demonstrate its significance to safe drinking water operations in areas where fluoridation is a significant problem. We mainly focus on fluoride contamination instead of other water contamination problems because fluoride contamination is by far one of the challenging and significant prevailing problems in a developing country like Pakistan. The relevance and viability of the business model for de-fluoridation in affected regions will be a guideline for other water contamination issues.

BUSINESS MODEL LOGIC

A business model is a strategic plan that seeks to address fundamental questions like how to generate profits, who are the customers, what are the products and services, and how to deliver and capture value at appropriate cost[8–10] Businesses models combine both quantitative and qualitative assessments in terms of financial returns and business operations. The viability of a business depends upon the quality of products and services it offers, the satisfaction level of its customers, and the business's ability to link its technical know-how with the socio-economic problems required to create value for its customers[11].

Although business models were first used and applied in the e-commerce sector, they are now widely used in all sectors, including markets and industries in developing countries[10,12]. In addition, we assume that applying business-model-logic to safe-drinking-water demands in developing countries has a great chance for success. Creative thinking and creating business development models are critical to developing sustainable services to fulfil basic human needs[2] in a developing country like Pakistan. Business model logic can address basic human needs and services, like safe drinking water, sustainably[13].

Using Business models for safe-drinking-water supply services

Small and medium businesses providing water delivery services are gaining momentum in areas with sizable populations. These private water treatment businesses efficiently and sustainably utilize their resources and make returns on their investments, continuing their business ventures[14]. However, publicly-owned water treatment services need consistent services and subsidies to continue operations[15]. Water delivery from boreholes and water kiosks to final consumers is reported and documented in South America, Sub-Saharan Africa, Nigeria, and India[1,16]. Private businesses providing water services are substantially effective in areas lacking access to safe water. In addition, a suitable business model can solve the problems associated with safe-water service provisions even in remote rural regions of a developing country like Pakistan.

In the past several decades, substantial work has been made to study and reform water supply services in populous areas in a developing country like Pakistan. Unfortunately, limited attention has been paid to safe water service provisions in rural areas, and more attention needs to be paid to the increasing problem of water fluoridation.

Financial, technical, social, environmental, and institutional factors constrain the sustainability of safe drinking water[17]. Safe water supply schemes in Pakistan face several problems, e.g., financial, infrastructure, technical, institutional, management, environmental, socio-economic, and operational challenges[17], etc. Due to all these problems, the number of developed but non-functional safe water supply schemes is high[18].

This study investigates how business models can highlight and solve the prevalent problems in safe drinking water supply. Technology is the most critical and crucial part of the safe water supply process, so our study mainly focuses on the technology side of the business model for socio-economic sustainability. This study will provide a foundation for building sustainable, safe water provisions.

The Thar Desert in Pakistan is identified as a highly fluoridated area; fluoride concentration in the drinking water is reported to range between 7–32 mg/L in Thar Desert[19,20], while in the Quetta valley of Pakistan, the fluoride level is reported to range between 2.5-24.0 mg/L[21] significantly above the recommended level by WHO. Apart from skeletal and dental problems, fluoridation significantly impacts the socio-economic well-being of the people due to skeletal fluorosis. Furthermore, fluorosis-related issues are widespread and stigmatize the entire population in the affected areas[1,22]. Previous studies reported skeletal fluorosis in communities up to 65.7%, 56.87%, 43.13%, and 54.5%, respectively[1,23,24]. We conducted our study in the Thar desert area and the Quetta Valley of Pakistan; this study's results will apply to other developing countries. The business-model-logic is applied to scale up the setup of sustainable, market-oriented de-fluoridation systems to ensure wide access to safe drinking water.

DEFLUORINATION SYSTEMS AND TECHNOLOGIES

The bone char and Nalgonda techniques, among available technologies for de-fluoridation of water, are the most commonly used and employed in underdeveloped countries such as Pakistan, India, Kenya, and Tanzania[25,26]. The Nalgonda method originated in India and combines aluminum salt, bleaching powder, and lime, mixed rapidly, followed by flocculation-sedimentation-filtration and disinfection. Aluminium salt can be aluminium chloride, aluminium sulfate, or a combination of these compounds. The cow bone-based (bone char) technique, in which cow bones are processed to transform into porous and carbon-rich compounds, is effective for de-fluoridation water. However, the bone char technique still needs further improvements and enhancement due to its low capacity for de-fluoridation. Another medium cow bone media developed by Yami et al.[27] Chemical activation of cow bone instead of the thermal activation of cow bone used in Africa showed significant and promising results compared to the bone char technique. Another system for removing fluoride is electrolytic delfuoridation (EDF), which uses electrodes through water, causing fluoride ions to separate and be removed. The current study selected the EDF, chemically activated cow bones (CAB), and Nalgonda techniques for comparison through the business model methodology.

Challenges in the existing de-fluoridation techniques

Minimal efforts and resources are utilized to address the problems of fluorosis in developing countries[22]. For instance, due to financial and technical constraints, the de-fluoridation of drinking water in Pakistan is not feasible and sustainable in the long run for large areas of the populace. Nevertheless, de-fluoridation systems can be considered at small community or household levels. A study by Rafique et al.[28] used activated alumina in the de-fluoridation water in Pakistan and found profound results in their experiment. Still, this de-fluoridation technique's logistics cost, maintenance cost, and operational constraints are high. Several factors attributed to the poor sustainability of previous de-fluoridation systems: chemical cost, inadequate management capacity, insufficient supply chain of chemicals, inadequate financial management abilities, and lack of skilled workers to install and run these water treatment systems[1,16]. Furthermore, the lack or limited involvement of the private sector in de-fluoridation is hindering the sustainability of the developed de-fluoridation technologies.

Business model for treatment of fluoride in the drinking water

In the current study, the EDF (aluminium electrode), CAB (chemically activated cow bones), and Nalgonda technique (aluminium sulfate and lime) were selected for comparison through the business model methodology. The projected business model (Figure 1) will help the companies assess the challenges associated with these different water treatment technologies and where they can most likely achieve sustainability.

We discussed and considered five essential business model components in the current study.

Unique selling proposition

USP is the distinctive value created and offered to the customer; it’s why a customer should choose a particular product or service[1,3]. De-fluoridation technologies in developing countries can be a game changer in terms of cost-saving benefits by avoiding paying for the treatment of health problems incurred from drinking highly fluoridated water. People in a developing country like Pakistan are exposed to skeletal and dental fluorosis[29] and have to pay medical bills despite their low-income category. Moreover, skeletal fluorosis will restrict people’s mobility, resulting in productivity and wage losses.

The suggested business model analyses potential cost-savings that can be accomplished by delivering fluoride-safe-water to people. According to our analysis, de-fluoridation technologies can help a household save an average of $378 per annum in medical expenses, productivity, and labour losses (Figure 1, Table 2).

Customers

The targeted consumers are the men, women, and kids living in the Thar desert, the Quetta Valley (about 5.4 million people), and surrounding areas. Moreover, schools, colleges, hospitals, and public and private sector institutions are among the targeted entities. The expected customers for the de-fluoridation systems belong to rural, peri-urban, and urban areas, with an estimated 500 to 1200 households living within a 3km distance from the water treatment facility (Figure 1, Table 2).

Cost Distribution

The cost of a successful de-fluoridation system involves key activities like manufacturing, installation, adsorbent production and distribution, the distribution of fluoridated treated water, developing a customer base, and marketing.

Revenue generation

Revenue is the income collected for the sustainable value the business offers[9,30]. Our business model's revenue generation mechanism is based on the fee collected from customers for providing fluoride-treated water and adsorbents and extending fluoride treatment to nearby communities. Additional income is expected from services like designing, installing, capacity building, and training customers, local governments, and communities.

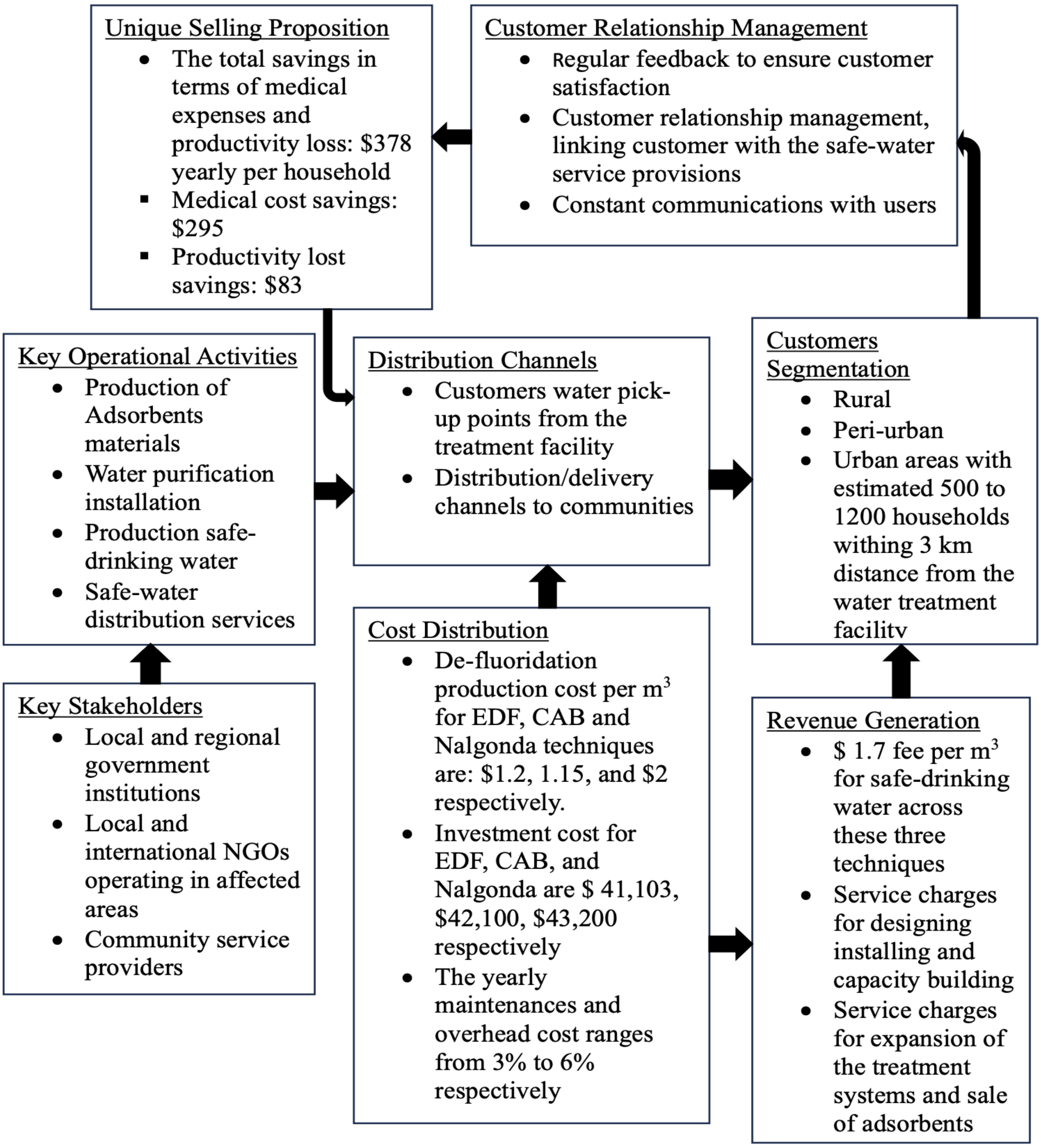

Figure 1. The suggested business model for fluoride-safe water services.

Note: The estimated population density in the Thar desert is 83 per km^2, while in the Quetta Valley, it is 658 km^2, according to the Pakistan Bureau of Statistics 2017 census.

The USD to PKR conversion ratio was recorded at USD 1= PKR 278.71 on August 7, 2024.

Table1. Economical comparison of the fluoride treatment systems in Pakistan

	De-Fluoridation technologies		
Description	EDF	CAB	Nalgonda
De-fluoridation Cost (per m^3)	$1.2	$1.15	$2
Annual Production cost of treated Water (Per m^3)	$12400	$8200	$8500
Annual revenue generation from Selling treated water	$7800	$7500	$7700
Annual net profit	$4600	$700	$(800)
Assuming 30 water treatments operational Facilities, Annual net profit	$13800	$2100	$(2400)

Note: The USD to PKR conversion ratio was recorded at USD 1= PKR 278.71 on August 7, 2024.

Table 2. Cost calculation of de-fluoridation systems based on Demographic profile

Description	Quantity
Number of households for one water treatment facility	500 to 1200
Number of villages/municipalities for each treatment facility	4 to 6
Average number of people per household	5 to 6
Total number of people for each treatment system	10,000 to 43,200
Population growth rate in Thar desert and Quetta valley	2.62 % and 2.4%
Lifespan of the water treatment systems	15 to 20 years
Treated water demand per person a day	10 to 12 liters
Total capacity of treating water per day	20000 liters

Note: The data and numbers in Table 2 are based on a survey conducted in the Thar desert and Quetta Valley of Pakistan in the first quarter of 2024.

Table 3. Cost analysis summary for de-fluoridation systems

Description	EDF	CAB	Nalgonda
De-fluoridation System structure and components	$0.0604	$0.0294	$0.0377
Chemicals and material	$0.3402	$0.4714	$0.8891
Operational expenses	$0.501	$0.691	$0.9510
Maintenance cost based on 2% of treatment system cost	$0.302	$0.302	$0.398
Overhead/operating cost based on 5% of treatment cost	$0.0020	$0.0066	$0.0099
Total cost of fluoride-treated water per m^3	$1.2	$1.5	$2

Note: The USD to PKR conversion ratio was recorded at USD 1= PKR 278.71 on August 7, 2024.

Supply chain value network and competitive strategy

Supply chain analysis is a tool for evaluating and examining the different steps involved, from production to the delivery of product/service to end user, to identify areas for further efficiency and reduction of cost[31]. This will help the business transform its products and services into other forms of value to maximize their impact. Changing the business model over time due to market challenges, innovations, and legal constraints can help create a competitive edge that is hard to replicate. Moreover, the right design, implementation, and refinement of the business model is the key to a successful and sustainable business[9]. For competitiveness, the business model stratagem revolves around providing fluoride-treated water (1.5 mg/L, WHO standard) through sustainable services, supporting the local communities and government, and participating in water monitoring and evaluation.

To provide and expand the safe water supply to people, the planning process of the fluoridation systems must include partnerships with local government, local communities, and national and international NGOs. Generating funding for safe water supply from other than government entities, such as national and international NGOs, is important. Key stakeholders and partners in and outside the supply chain, such as suppliers, public/private entities, and the local community, will be identified, and training will be provided to increase their impact and engagement in the growth of water treatment facilities. A facility will be established to produce adsorbent by engaging private firm(s) and Local-service providers to manage the supply of chemicals and raw materials effectively. Safe water will be distributed by training the local service providers at distribution points. Local transportation means such as small trucks/minivans, horse/donkey carts, three/four wheelers, and motorcycle rickshaws transport treated water to distant communities.

Key components and assumptions of the business model

The key components and assumptions of the business model are as follows:

- Capital expenditures for infrastructure development, such as well digging, casing, pump installation, and electrotechnical equipment, common across the three systems (Nalgonda, CAB, EDF) selected in this study, are not included in the current analysis and comparison. The investment cost is presumed to be borne by the government, NGOs, or both.

- Similarly, the maintenance and replacement cost of the principal components, such as wells, generators, and pumps, is presumed to be borne by the government, NGOs, or both.

- A price of $1.7 per m^3 was determined across the three systems for fluoridate-treated-water to calculate the total-revenue from selling fluoride-treated-water, the value is determined after discussions with communities and research assessing affordability and willingness to pay in the Thar desert and the Quetta Valley of Pakistan.

- Operational expenses include the cost of chemicals, labour charges (salaries and daily wages), fuel charges, and overhead/operating expenses of the company running the water treatment facility. Overhead/operating expenses were presumed to be 5% of the total investment cost of the treatment systems.
- For the current study, communities in the Thar desert and the Quetta Valley of Pakistan were selected as target communities (Table 2). Data from these communities was used to analyze the cost of water treatment systems processes, revenue generation from water supply, and selling proposition.

RESULTS

To address the existing challenges of fluoride treatment systems in developing countries a business model was developed (Figure 1) depicting the comparison of the fluoride-removal-systems (CAB, Nalgonda, and EDF) via economic and business model concepts. The average cost per m^3 treated water for EDF, CAB, and Nalgonda is $1.2, $1.15, and $2 (Table 1 and Table 3). Table 1 shows that the total revenue generation for EDF is $7800, CAB is $7500, and Nalgonda is $7700. The yearly production cost of treated water for EDF is $12400, CAB is $8200, and Nalgonda is $8500 individually (Table 1). From Figure 1, we can observe the total saving of $378 a household can save in terms of medical expenses and productivity losses when they use water with a safe fluoride level. Net profit for EDF is $4600, CAB $700, and for Nalgonda ($800) is reported in Table 1. Tables 1,2 and 3 present the comparison and estimates of the three systems (EDF, CAB, and Nalgonda) using economic and business model concepts. The comparative analysis of these fluoride treatment systems is based on the literary evidence, research, and surveys conducted in the Thar desert and the Quetta Valley of Pakistan in the first quarter of 2024. The findings are summarized in table 1,2 and 3.

DISCUSSION

The results of this study suggest that EDF and CAB are more favourable options for fluoride treatment due to the lower cost of installation, production, and operational management. Furthermore, these two fluoride treatment systems' annual return on investment rate is higher than Nalgonda's (Table 1). In addition, EDF and CAB's fluoride removal capacity is better than Nalgonda's. The amount of sludge produced by the EDF fluoride treatment system is very low compared to the Nalgonda system, while CAB produces no sludge.

Communities living in the Thar desert and the Quetta Valley pay a substantial cost for fluoride-treated-water at some water treatment facilities, although the treated water does not fulfil the WHO criteria of 1-1.5mg/L fluoride (Survey conducted by authors in the first quarter of 2024). Our survey shows a high demand for fluoride-safe water among communities in the Thar desert and Quetta Valley. Some communities were paying much higher prices for water fetched from distant sources when there was a water shortage in their area; the willingness of these communities to pay more for fluoride-safe water was evident. The proposed profitability of these fluoride treatment systems, along with cost savings on medical treatment and productivity losses, will encourage the government to support the extension of these water treatment systems. In addition, this will encourage the private sector to adopt and invest in the proposed business model.

The ongoing health issues associated with fluoride and the lack of sustainability in the fluoride treatment system are forcing researchers to find innovative and market-oriented solutions[114]; our study is an extension of these efforts by proposing a business model entrepreneurship approach for fluoride safe water service provisions for local communities. Comparing fluoride treatment systems, the prerequisites of the business models, such as customer demand, sociocultural elements, and financial aspects, were considered for value creation and delivery highlighted by Baden-Fuller et al.[8]. The proposed business model highlighted the key partners, key resources, customer segments, cost involved, and revenue generation in fluoride-safe water service provisions.

The proposed business model focuses on the potential joint ventures with local service providers for the production and installation of the treatment facility, fluoride treatment, chemical supply, distribution, operations, and management of the treatment facility (Figure 1). A business model connects different interdependent activities for creating and delivering value, as demonstrated by Climent et al. and Shafer[9,32]. The current study highlighted the usefulness of the business model as a tool to encounter the challenges in safe-water supply provisions. Through business models, we can support the expansion of safe-water technologies and ensure economic and financial returns and realizations.

To counter existing challenges in the safe-water supply services, market-oriented solutions should be developed for the current crisis in safe-water supply by involving local government, NGOs, communities, and academic research. Additionally, the private sector plays a significant role in expanding de-fluoridation systems. However, incentive mechanisms such as developing business-friendly policies, credit mechanisms, financial returns, and tax rebates should be in place to encourage the private sector and maintain their motivation.

CONCLUSIONS

The study predicts a $378 yearly savings per household for averting medical costs and productivity losses using fluoride-safe water. In addition, the study demonstrated how a business model can be an effective tool to assess the feasibility of different fluoride treatment systems in safe-water service provisions. According to our research, the EDF and CAB fluoride removal techniques are more cost-effective and generate higher profit than the Nalgonda fluoride removal technique.

Based on our study, policymakers and water service providers should adopt the EDF and CAB fluoride removal technologies to maximize economic and health benefits. Future research should focus on the long-term sustainability, scalability and community acceptance of these delfuoridation methods. Furthermore, future studies should explore ways to incorporate these techniques into existing water fractures.

CONFLICT OF INTERESTS

None

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