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Climate-Resilient Solutions: The Anticipated Role of Reed Bed Technology in Transforming Rural Hygiene and Waste Treatment in Pakistan

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Abstract
Introduction: Reed Bed Technology (RBT) is a cutting edge green technology in wastewater treatment. It has been accepted as a sustainable and cost-effective in response to the problems of waste disposal, hygiene, and climate change in rural areas of developing countries including Pakistan. It applies natural wetland plant such as reed to detoxify the wastewater and produce valuable products for agricultural uses. **Problem statement**: Due to lack of its exploration in the context of Pakistan and its potential business avenue strengths, a gap existed which needed further exploration. **Research Methodology**: This paper explored the effectiveness of Reed Bed Technology with special reference to its application in rural areas of Pakistan. Information for the paper was collected through case studies, visiting rural location in context of Islamabad as well as from various research articles that show the effects of RBT on waste treatment and about RBT long-term business among the communities. **Findings**: RBT contributes a lot to sanitation and hygienic conditions since it minimize on water borne illnesses and emissions of pollutants into the environment and treated water can be used again in agriculture to encourage the circular economy. **Recommendations**: Further, due to the low cost of the technology and the ease and simplicity of implementation, such solutions can be implemented for rural areas and create zone employment and entrepreneurship for sustainable waste management and resource recovery. To ensure the long-term utilization of RBT, training and awareness programs in rural Pakistan should be launched in the country.

Keywords: Reed Bed Technology, rural Pakistan, Climate Change, Community hygiene, Entrepreneurship.

Introduction

Reed Bed Technology (RBT) is on the growing list of interest in environmentally friendly water management system; most probably in rural parts of developing

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countries. RBT fully embraces the use of natural wetlands and specific plants like reeds as the major driver in waste and wastewater treatment, thus pioneering a cost-effective and environmentally friendly technology (Sharif et al., 2017). Unlike the conventional sewerage system it not only deals with hygiene and sanitation concerns but also provides useful qualities such as treated water and oily substances that could be useful for farming, hence making it cyclic. Reed Bed systems therefore present a sustainable solution to the conventional wastewater treatment systems that although are complicated and costly. Since reed plants can filter and treat wastewater naturally, this technology is rather affordable for communities with a scarce amount of investment and architectural means (Tan et al., 2023).

Reed Bed Technology works under the principle of how wetlands have been used historically for water treatment and purification. Wetlands consist of a complex community of the plant, microorganisms and sediments which help in purification of water. In this context, while Reed Bed systems are themselves now artificially designed as a natural process, it is the natural abilities of specific aquatic plants, or at least reed species, such as Phragmites australis, to deal with wastewater that has been harnessed here (MJ, 2023).

The initial designed Reed Bed systems were developed in the 1960s and 1970s in Europe because of high pollution levels in water bodies across expanding cities. Today, Reed Bed systems have gone through many changes in terms of design and operations, over the decade (Parmar et al., 2016). Which were originally used for municipal wastewater treatment, are now used in industrial processes, agriculture waste water treatment and even grey water treatment (Unicomb et al., 2018). Currently, Reed Bed Technology is considered as a fundamental part of Integrated Sustainable Waste Management solutions where centralized Sewerage Systems are not available in areas such as rural or remote areas (Al-Ajalin et al., 2020).

Pakistan is facing through some of the most severe challenges today in the history of mankind i.e. Climate change (Bhatti & Iftakhar, 2023). With being the 5th most hit and vulnerable nation, opting for sustainable solutions to cope with these devastating situations resulting from droughts, flooding, severe heat waves and other challenges (Zainab et al., 2023). It is need of the hour to opt for those solutions which are cost effective, easy to deploy, long lasting and can also be transformed into the potential local business for entrepreneurship models as well (Kumar et al., 2019). This research this focus on the exploration of the RBT potential towards a solution for the rural Pakistan issues arising from waste water poor treatment and hygiene issues.

Hence to carry on forward with the research exploration, following major research objectives were set forth:

1. To evaluate the current knowledge amongst the selected rural settings about the RBT.
2. To evaluate as per review of literature how these awareness and sensitization challenges could be improved.
3. To propose future research and exploration direction to help better evolve strategies for future RBT deployment in rural settings of Pakistan.

The study was able to not only achieve the targeted objectives stated above but also critically identified the most reasons for the gaps yielding better future outcomes. The paper would compliment any other strategy which may align

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towards RBT usage as well as feasibility for future potential usage in rural areas of Pakistan.

Review of Literature

Climate change is a greater threat to mankind today then ever before and has transformed into a major issue for the current and future generations sustainability (Bhatti et al., 2024). With rise in challenges of resource management across the developing nations, Pakistan is a major country hit severely by climate change and hence needed much attention towards resource management and its optimization (Bhatti & Iftakhar, 2023). Reed bed system is an environment friendly wastewater treatment system that uses concepts of wetlands to deal with sewage, industrial effluent or storm water. It employs the ability of the biological, chemical and physical interactivity of the microorganisms, plant and the soil to filter water (Mani et al., 2019). It is more functional than most other methods, and it is a low-cost option that works well in areas that are not close to industrial cities with standard wastewater treatment plants. The essence of the reed bed technology can be described as planting selected water tolerant species, particularly the Phragmites australis common reeds, in a specially designed channel with layers of gravel or sand, or soil (Chatterjee et al., 2019). It means that water to be treated percolates through the bed and has to be clean because of microorganisms living on the roots of the reeds and beneath the substrate. In due course of time the contaminants appear to change into other non-harmful products like carbon dioxide, nitrogen and water (Sathyapriya et al., 2019).

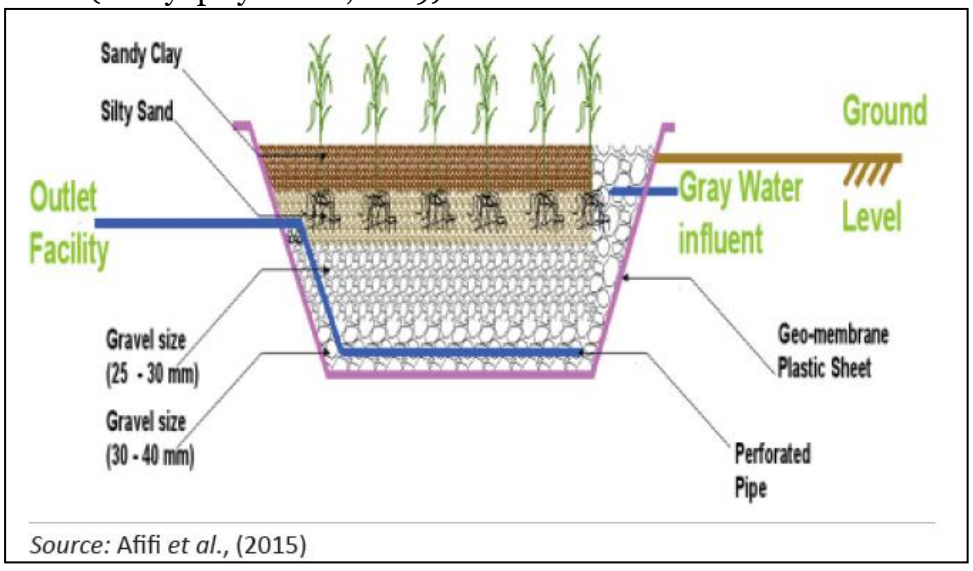

Figure 01 Reed Bed Technology concept (Afifi et al., 2015)

There are primarily two types of reed beds:

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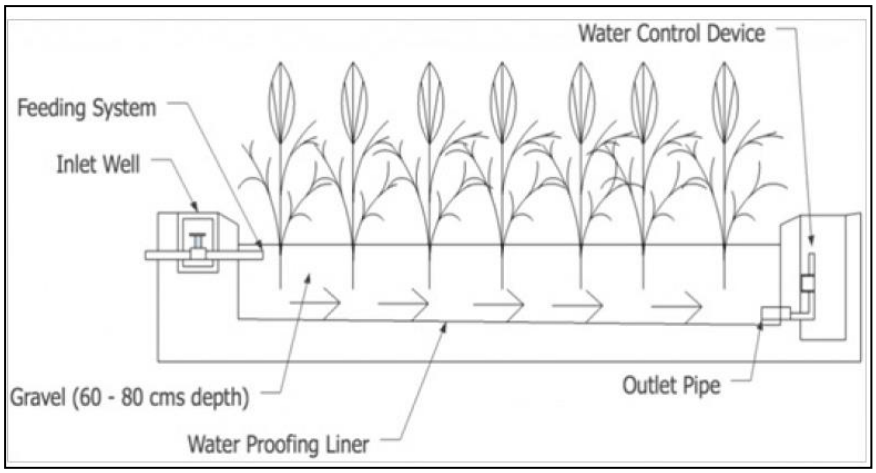

Figure 02 Horizontal Reed Bed Technology(Afifi et al., 2015)

Horizontal Flow Reed Beds: Water is carried horizontally over the substrate so that anaerobic bacteria can break down the organic matter material. These beds are effective in the removal of total suspended solid, nitrogen and some forms of pathogens (K & Chinnusamy, 2019).

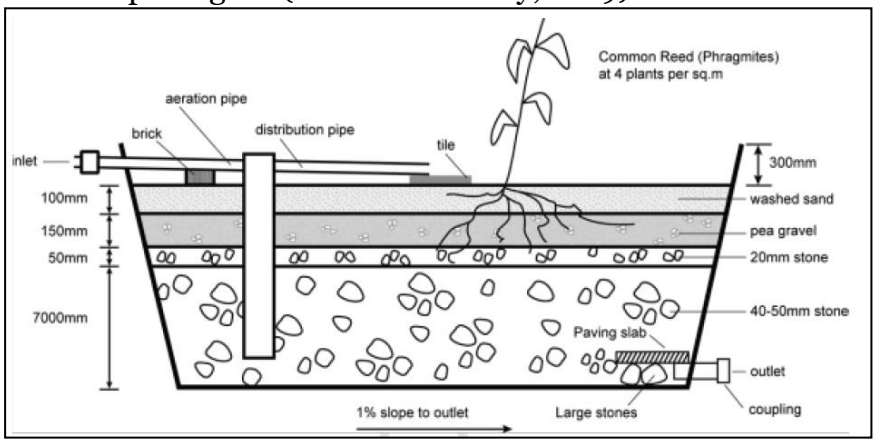

Figure 03 Vertical Flow Reed Beds (Afifi et al., 2015)

Vertical Flow Reed Beds: In this system, wastewater is applied from the top in order to percolate through the various layers. The aerobic bacteria that are engaged in the upper layers effectively deal with the water. Vertical flow systems appear to be superior to the horizontal ones in terms of their oxygenation potential as well as the efficiency exhibited in the removal of organic loads and nitrates (K & Chinnusamy, 2019).

Another common design is of a mixed horizontal and vertical flow reed bed system for the purpose of overall treatment (Gustavsson et al., 2007).

Usage of Reed Bed Technology

Reed bed technology is versatile and serves a number of objectives and its primary use is in the treatment of wastewater. It has been used in the following areas (Kumar et al., 2019):

1. **Domestic and Municipal Sewage Treatment**: Designed constructed wetlands such as reed beds are an effective means of managing household and small community wastewaters. The use of reed beds can be of great

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benefit in areas not served be conventional efficient sewage system in the management of organic wastes.

2. **Industrial Wastewater Treatment**: Many industries including dairy, breweries and paper industries generate large quantities of wastewater. This water can be treated by Reed bed technology before it is let off into the natural system.
3. **Agricultural Wastewater**: Farms have the ability to use reed beds to remove water from the fields, barns, and livestock regions and lessen the nitrogen and phosphorus that gets into the bodies of water.
4. **Storm water Management**: There are several difficulties with regulating storm and destroying water in urban territories; this water contains pollutants and often enters rivers and lakes. One use of reed beds is that they can be incorporated into the layout of urban areas for purposes of treating and purifying storm water.
5. **Sludge Dewatering**: They also hold and treat sewage through dewatering and sludge stabilization thus cutting the quantity of sludge to be dumped.
6. **Wetland Conservation and Restoration**: Being shallow water system, they can be used to renovate damaged environment or establish artificial wetlands in the unsuitable habitats.

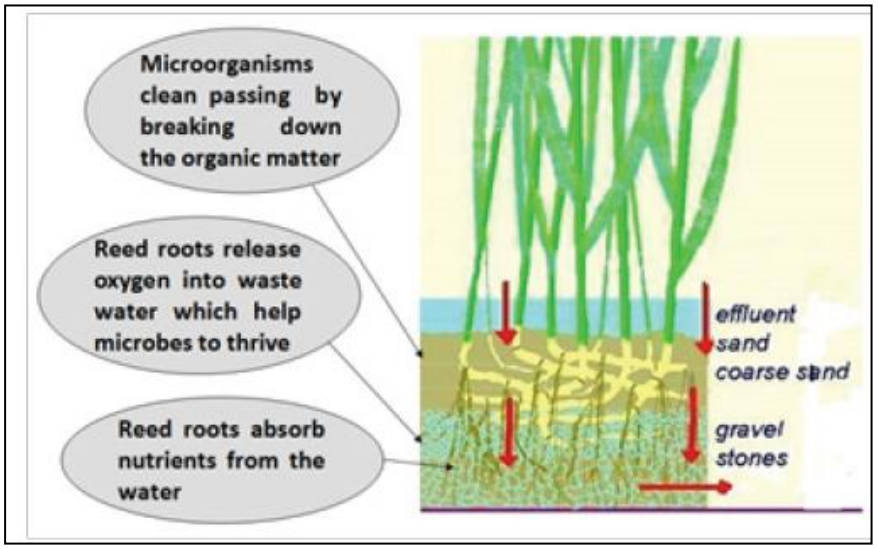

Figure 04 Overall functionality of Reed Bed Technology (Garcia et al., 2004)

Despite its numerous advantages, reed bed technology faces several challenges (Masciandaro et al., 2015):

1. Land Requirements: Reed beds are large structures hence cannot be useful in densely populated areas such as the urban areas where space is a major issue.
2. Seasonal Performance: Of course, there will be reduced performance in the reed beds during cold climates or during phases of high rainfall. Plant reeds have the feature of slow growth in the winter season thus decrease the overall capacity of the system.
3. Slower Treatment Process: The treatment system in these reed beds is very slow as compared to normal treatment plants because this is not intended for the provision of a high capacity of water treatment in a shorter period of time.

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4. Clogging: Humm Further, the gravel and substrate applied in reed beds tend to become blocked over time, more so if the water holds heaped loads of solids. This is expected to happen and regular checkup and scrutiny is mandatory to avoid it.
5. Design Limitations: It is mainly on this premise as issues to do with the design and construction of the reed bed systems play a big role in the overall success of the system. Defective design of reed beds causes poor treatment efficiency and pollutes the environment.
6. Lack of Expertise: One of the major challenges associated with the widespread use of this technology is shortage of skilled personnel in many areas for design, installation and maintenance of reed beds.
7. Public Perception: Due to their likeness to wetlands, the reed beds may be viewed as unhygienically dirty or CSI: smelly. To address such issues, people need to be educated, enlightened on the issue so that they can reverse the vice.

Research Methodology

Based on the core concept evaluation and clarity, the research moved ahead with a defined research methodology to ensure all information flow be managed and ensured to opt for a clarity of outcomes success as well as objectives completion. A mixed method research approach was used where secondary data helped devised open ended questionnaire to be answered by people in the selected rural settings towards awareness, inclination and optimization in future usage for RBT. Convenient sampling was used and sample mainly consisted of 25 different resource persons in the context of twin cities of Pakistan in rural settings towards future usage and prioritization.

Based on the data gathered and the feedback of respondents, research findings were developed which guided towards future directions of research and the potential transformation of the people to use RBT in their settings for better environmental outcomes.

Data Collection & Analysis

Site Surveys and Fieldwork

Data collection from respondents was carried out at multiple locations and these mainly included the following:

1. Alipur Farash
2. Chak shahzad
3. Changi syedan
4. Sihala
5. Malpur
6. Tarnol
7. Sohan
8. Saidpur
9. Shahallah dita
10. Pind Begwal

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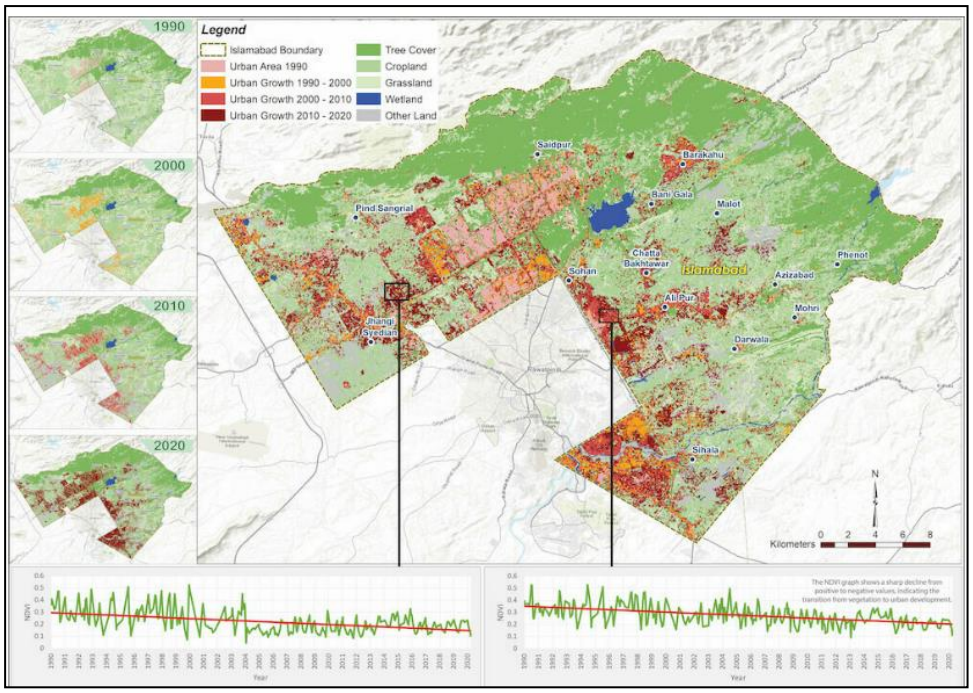

Figure 05 LCLU transformation of Islamabad from 1990 to 2020 (WWF,2022)

Based on the review of literature, the overall open ended questionnaire mainly consisted of the aspects related to awareness, knowledge, prioritization and future deployment. The respondents response is discussed as below:
Although reed bed technology has significant potential, its use in Pakistan remains limited due to several factors:

1. **Low Awareness Among Stakeholders**: Most of the policy makers in Pakistan those who belong to government departments, planning agencies and engineering fraternity are seemingly unaware of reed bed technology. Therefore, despite the fact that setting up a reed bed may be more efficient and cheaper than a traditional treatment plant, the later remains the option of choice.
2. **Financial Constraints**: To date, most of the communities, especially those in the rural setting, grapple with issues of inadequate funds. By its nature, reed bed systems require a subsidy or some financial assistance from the government or international bodies to popularize and implement.
3. **Preference for Conventional Systems**: As for the urban settings, they prefer using the conventional wastewater treatment plant due to perceived higher effectiveness and reliability even when their operational costs are higher and their impacts on the environment are much severe. The engineers themselves and the construction companies involved do not fully understand the application of reed beds leading to their limited use.
4. **Technological and Infrastructure Gaps**: The technologic support system to design and implement the reed bed systems at least in Pakistan is in relatively limited trend. He added that there is a scarcity of professionals specialized in water management and natural

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wastewater treatment systems have not been paid much attention in universities and research facilities.

5. **Land Scarcity in Urban Areas**: The population density of Pakistan is extending its impact to urbanization that is again a factor of shrinking area for availability of raw land. Since the reed beds system requires large expanses of space, implementation in areas of high human density such as the cities, becomes a challenge. This leads to an appreciation of small, advanced technology-based systems for wastewater treatment as opposed to natural systems.
6. **Climatic Challenges**: Different regions experience different weather, while some areas are extremely hot during the summer others experience winter. These climactic changes could compound on the effect on growth of the reeds as well as the treatment efficacy. It may also be important to note that in areas of high temperature such as hot arid regions more planning, research and development may be necessary for the proper functioning of the reed bed systems.

Discussion & Analysis

This data exploration identified the challenges towards Reed bed technology utilization and deployment, which otherwise has the possibility of being an effective and cost efficient method in the treatment of wastewater in Pakistan. Knowledge and awareness is an important aspect; the low level of awareness of policymakers, planners, and engineers is a more important problem. These stakeholders continue not to be informed of the advantages brought by the reed beds, preferring conventional, expensive treatment plants which have the disadvantage of giving a greater impact on the environment and a higher cost than the reed beds ones.

It's also worthy mentioning that funding influences implementation since many endusers are from the rural areas of the country that lacks the necessary resources to pull off the implementation of policies. It is believed that the construction of reed beds typically may be possible only with governmental or international support. Urban area, however, resort to traditional systems due to their perceived reliability even though their operating costs and the negative impacts on the environment are high. Engineers and contractors again lack sufficient technical knowledge on the use of reed beds to expand its use.

Besides, Pakistan lacks technological and infrastructure management capacity with a scarce knowledge of water management and natural wastewater. Unfortunately, educational institutions have not paid much attention to these systems, which are a severe shortage of professionals. Another big problem is the often limited availability of land, especially in the most densely populated areas of the world, to which reed beds must be planned on a large scale to be effectively utilized. Therefore, the local authorities prefer using compact and technologically advanced systems that may be integrated into tight spaces.

Last but not the least, climatic factors pose a major concern to the performance of reed beds. A number of factors which influence reeds growth and the overall treatment process include environmental factors such as fluctuating climate of Pakistan which has extremely hot conditions and extremely cold winters of short span in most of the central and northern parts

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of the country. Further investigation might be necessary to the effects of climate in extra cold or hot areas and in how these conditions can greatly affect the efficiency of using reed bed systems.

Research Findings

Following were the major research findings of the project:

1. **Analysis on the performance of Reed Bed Technology:** Recent studies established that reed bed systems are very efficient in greywater treatment. Research shows that system exists, capable of treating wastewater biologically; by retaining, reflecting, absorbing through plants, soil as well as microorganisms. For example, treatment through reed grass such as Phragmites karka is proving efficient in separation of wastes in grey water system, and turning it into clean water with measurable impacts on the environment in Pakistan.
2. **Cost-effectiveness:** Another major benefit of using reed bed technology is that this system requires very little operating and maintenance expenses. These systems can operate using cheap reagents, fuel, or equipment, thus they are appropriate for rural settings where resource inputs are scarce.
3. **Sustainable Development and Impact on the environment:** Reed bed technology is sustainable by nature and it has implication on the achievement of sustainable development. It is useful in reducing pollution of water by untreated sewage; a nuisance that is prevalent both in the developed and the developing Pakistan. Integrated aquatic ecosystems cut down the pressure on the environment because the wastewater is purified naturally, and as such, the water in near rivers and lakes is not polluted.
4. **Inconsideration of the local endowment and circumstances:** From this, researchers find that reed beds can be varied according to the climatic region of the Pakistan. Several species of reeds have been tried out and each species has been found to grow in local environmental conditions, thus making a versatile growing structure for rural and coastal areas.
5. **Challenges in Adoption:** Even though reed bed technology has a great potential in Pakistan it is still not much used. The barriers include poor awareness, inadequate technical experience, and high costs in rural settings. Furthermore, the current being used in wastewater management in Pakistan is discharge of untreated wastewater in to natural water sources, which is an aspect that is believed to have compounded pollution.
6. **Climate Resilience:** They have demonstrated flexibility in the controlling of climate change impacts more so in the coastal areas. They refill water sources such as ground water and purify the water that is from human activities hence protecting environment by curtaining impacts of climate variability such as floods by taking in high levels of pollution.

Recommendations for Future

1. **Policy and Awareness Programs:** In order to increase the use of the reed bed technology in the rural areas, therefore, Pakistan needs to embark on serious consciousness raising efforts. Applying technological enhancement to reed bed systems, and promoting the awareness of local

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communities, policy makers, and engineers about the capability of reed bed systems can contribute to its higher application. Such opportunities as the workshops, public demonstrations, and training programs can very well demonstrate the cost savings, sustainability features and easy implementation of such systems.

2. **The government incentives and financial support:** Availability and cost of capital remain an area challenge for installing reed bed systems in rural areas. That is why the government can offer subsidies or low-interest credit products to adopters. Also, there is an opportunity to establish a partnership with the int'l organizations aimed at management of water resources in order to receive grants and technical assistance.
3. **National wastewater policies:** Reed bed systems should form part of the national wastewater management plan in Pakistan. In this way, the government acknowledging them as an official solution for small-scale communities and rural areas, can promote their use in areas where large scale wastewater disposal plants cannot be built because of high costs or constraints in infrastructure.
4. **Research and Development:** Further research is also needed to fine tune some of the features of reed beds for different conditions in Pakistan. Institutions and universities should possibly dedicate their research efforts on efficiency designs, examining various plant kinds, and scalability systems. This can result in improved compatibility and sensitivity to the local constraints, and hence improve the efficiency of the system in different parts of the world.
5. **Training programs for Engineers and planners:** Hence, there is need for a technical team who will implement the reed bed technology . The Pakistani administration should support courses in engineering, architecture and planning that would provide necessary information to build such systems in the rural as well as the urban context.
6. **Community-Driven Projects:** As much as possible, local communities must be given the challenge to manage their tame wastewater treatment using reed bed system to improve the chances of success. Since the communities are encouraged to be part of planning and even maintaining the systems, the government getting it right improves the longevity of the systems.
7. **Integrating Reed Beds with Other Green Technologies:** Reed beds can then be linked to other green technology devices like the solar pumping of water or even rain water collection tanks to make the water management system even more effective. It can therefore assist in solving water problems such as shortage of water whilst proactively working toward better sanitation in rural areas.
8. **Solution for Climatic challenges:** On this note, the government should engage in a regional-based study carried out to check the efficiency of reed bed systems in the different climatic regions of Pakistan. In regions characterized by very hot or cold climate, or the absence of water resources, special systems or types of plants may be required. Awareness of such climatic effects and control of these climate vagaries will enable reed beds to be a more dependable solution in the entire country.

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9. **System of monitoring and evaluation:** In order to achieve the sustainability of the reed systems in Pakistan, it is high time for Pakistan to establish monitoring and evaluating system. These systems can map the performance of installed reed beds, explore possible improvements, and make certain that it keeps to work efficiently. Its periodic check will easily help pinpoint certain issues such as blockage or poor straining hence early corrective measures have to be taken.
10. **International Collaboration:** Pakistan can benefit from adopting the technology of reed beds in the international form. Successful examples of having implemented this technology can be ideologically used to learn from and adopt from such countries as Pakistan can do. Integrated works can likewise produce prospects for support and funding, which will speed up the adoption of reed bed systems in rural decent.

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