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A SPATIAL MODEL TOWARDS RENEWABLE ENERGY AND WATER SAFE VILLAGE

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Abstract

The increasing consumption of non-renewable energy and consequent global warming calls for use of renewable energy at scale. Bangladesh is moving toward ensuring renewable energy for all households by 2025 and has already been ranked 2nd in the world in providing off-grid solar home systems. Yet, national energy generation is largely dependent on fossil fuels and covers about one-third of the rural households. Driven by thriving economic development, villages of Bangladesh are experiencing rapid socio-economic-spatial transformation. However, most of the rural population lives with short of energy and safe water which is the main obstacle in sustainable transformation of rural settlements. To compensate for this shortage, they rely on traditional renewal energy sources such as biomass and solar energy to meet their daily needs. Regarding this energy-water scenario, this research aims to explore the potential of planning renewable energy integrated homestead from a physical-spatial design perspective taking a typical village as the case. With a multidisciplinary-exploratory approach the research is designed with a two-fold methodological framework: 1) investigation of existing energy status (consumption, needs and affordability) and water security (usage, sources and quality); 2) mapping spatial patterns of available energy and water services; and 3) exploration of existing homestead morphology to examine the scope of integrating renewable energy and rainwater harvesting systems in an efficient and cost-effective manner. Based on the triangulation of findings from these investigations, the research develops a Renewable Energy and Safe Water Integrated Spatial Model towards sustainable transformation of rural settlements.

Keywords: Renewable energy, Water security, Physical-spatial considerations, Sustainable rural transformation

Introduction

Nowadays, one of the biggest challenges in the world is to meet the growing energy demands in an environmentally efficient and sustainable manner, especially in rapidly developing countries with their rising populations and rapid urbanization. With the pace of this growing energy demand, the consumption of non-renewable energy is also escalating dramatically, resulting huge energy crisis for future sustainable development. Global primary energy consumption is expected to rise by 36% between 2011 and 2030, with an

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annual growth rate of 1.6 percent, in which fossil fuel will dominate 88% of the total energy supply (Ruhl, 2013).

Bangladesh is a developing Southeast Asian country with one of the lowest (321 kWh) per capita energy consumption rates (Islam, 2014). One-third of the power production of Bangladesh depends on expensive imported fossil fuel energy resources, which covers about one-third of the rural households, and 65% of power generation depends on the limited natural gas reserve of the country (Uddin, 2019). The Ministry of Power, Energy and Mineral Resources quotes that with a 160 million population Bangladesh government provides electricity to 70% of people in 2015 (Action, 2016). In addition, only 3 per cent people are enjoying piped gas supply (Chowdhury, 2015). There are more than 87,319 villages in Bangladesh, and most of them are not connected to the national grid system (Islam, 2012). Even though grid expansion is prohibitively expensive in rural areas due to looming capacity shortages (Islam, 2017), switching to renewable energy (RE) is currently a pressing need in Bangladesh to reduce reliance on nonrenewable energy sources.

Besides, driven by thriving economic development, villages of Bangladesh are experiencing rapid socio-economic-spatial transformation (Parvin, 2019). This booming economic growth and continual prospect in socio-economic development fundamentally relates to efficient and effective dissemination of, not only primary conventional energy sources but also alternative sources, as the formers are depleting (Islam, 2014). About 72 per cent people of Bangladesh live in rural areas (Chowdhury, 2015), where most of them live with short of energy and safe water which is the main obstacle in sustainable transformation of rural settlements. To compensate for this shortage, they rely on traditional RE sources such as biomass, solar energy and also rain water to meet their daily needs. Though hydrocarbon resources in the country are limited, the potential non-exhaustive sources of energies, available in the form solar, biomass as well as rain water can be spatially integrated to the off-grid isolated rural areas to provide affordable and environmentally sustainable energy and water security (Baten, 2009). In the absence of any stringent planning and land use control related to RE for rural areas, the traditional village morphology is continuously transforming (Alam, 2016). Facilitating greater dissemination and adoption of RE and improved energy efficiency technologies in these rural areas would be another feasible pathway for sustainable rural transformation (Dincer, 2015). Motivated by this auspice, effective utilization of RE resources has been adopted as a policy of the Government of Bangladesh especially in rural off grid areas. However, successful implementation of this policy requires comprehensive understanding of spatial physical planning regarding the integration of clean energy into the morphology of the villages.

Regarding this energy-water scenario, the research aims to explore the potential of RE-integrated self-sufficient village from a physical-spatial design perspective taking a typical village '*Choighoria'* as the case study.

Literature Review

The era of rapidly increasing anthropogenic climate change, with its greatest impact on vulnerable southern communities, compels us to prioritize renewable energy technologies (RETs) in order to ensure the long-term sustainability of global energy systems (Cloke, 2017). Bangladesh, a southern developing country, has been suffering from an energy and water crisis for several years despite having abundant renewable resources (Paul, 2022). Sources including biomass, solar power, and rainwater can be viable options for ensuring long-term energy and water security (Paul, 2022). The dispersed nature of rural settlements in Bangladesh provides an auspicious environment for the sustainable utilization of both renewable energy and water sources. According to the position of Bangladesh between latitude 20°34' and 26°39' north and longitude 80°00' and 90°41' east, it is an ideal location for the utilization of solar energy-based technologies, especially in the off-grid rural areas (Chowdhury, 2015). Besides, as an agro-based economy, Bangladesh has the highest potential for utilizing biomass energy sources, mainly from animal and municipal wastes, if it is appropriately harnessed considering the local cultural and technological contexts (Islam, 2014). Besides, being located in the Asian monsoon belt, it gets a large amount of rainfall (generally between 1,500 and 3,500 mm) during the monsoon, so rainwater harvesting has been considered as a prospective option (Sumon, 2014).

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The development and implementation of these renewable energy systems are intrinsically linked to spatial management (Stoeglehner, 2020). Stoeglehner (2020) also suggest that the radical shift in energy provision towards efficient use of renewable resources can only be achieved if its spatial-physical dimensions are taken into consideration. Only a few academic literatures address the spatial physical dimensions of RETs in relation to rural spatial morphology. According to Poggi (2018), due to low population density, the local spatial contexts of rural areas have a significant influence on how these renewable energy technologies are implemented. In this particular context, the issue of the use of land and its relationship with the spatial dimension of RETs is an essential sustainability criterion for the appropriate implementation of these technologies (Poggi, 2018). Therefore, the relative positioning, orientation (Chowdhury, 2016), effective use of space, and functional connectivity (Stoeglehner, 2020) determine the efficient implementation of these RETs in rural homestead morphologies.

Alarmingly, spatial-physical planning of rural settlements has never been given due attention in the policy context of Bangladesh (Parvin, 2019). In 1996, the first National Energy Policy (NEP) of Bangladesh was formulated, where priority was given to the planning and projection of decentralized RETs for the sustainable energy development of rural settlements. Here the emphasis is placed on socio-economic, environmental, and technical considerations of RETs. While the spatial-physical considerations regarding the effective use of decentralized RETs in isolated rural areas are excluded from the policy. Later in 2008, the government of Bangladesh adopted a Renewable Energy Policy with the aim of boosting renewable power generation. This policy emphasized the appropriate, efficient, and environment friendly use of RE; the dissemination of RETs in rural areas; and the development of local technology in the field of RE. Again, the spatial-physical considerations for implementing these RETs in dynamic rural morphology are significantly absent from the policy.

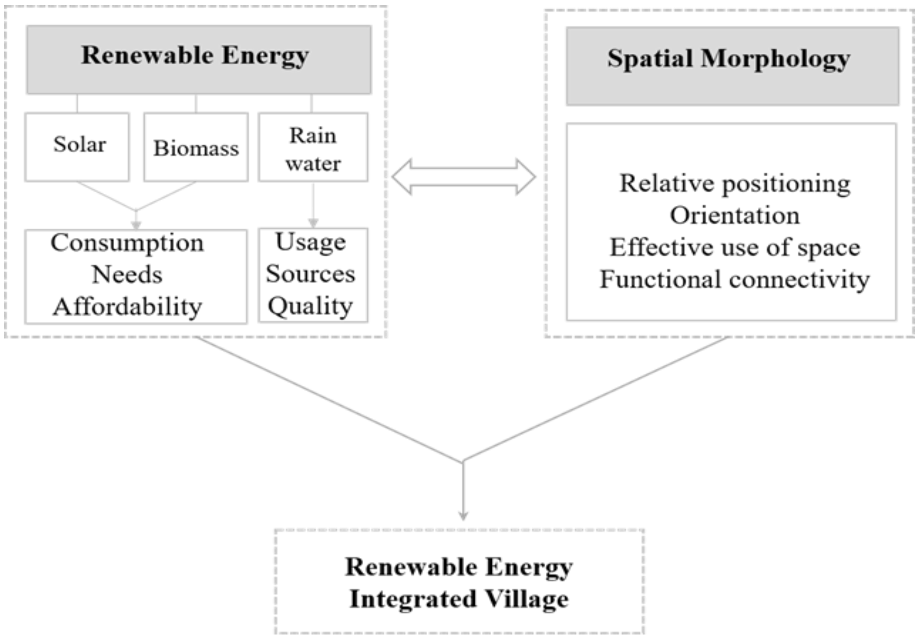

Figure 1. Conceptual Framework of the study.

Therefore, in rural areas, particularly for homesteads, the development of potential sustainable energy sources may be constrained by the lack of these integrated spatial-physical considerations. Since the available RETs and the rural homestead morphology are strongly correlated, this research is designed in such a way that unfolding this enclave is essential for formulating integrated physical-spatial considerations (See Figure 1).

Materials and Methods

This is an empirical study, based on the analysis and depiction of data related to existing available energy status based on consumption, needs, affordability and also the water security based on usage, sources and quality of the study area. To explore the existing spatial patterns of available energy and water services, four indicators (relative positioning, orientation, effective use of space, and functional connectivity) are taken into consideration. The study took a typical village named *Choighoria* (Figure 2) of Batiaghata Upazilla in the southwestern coastal district of Khulna Bangladesh. Empirical evidence confirms that the peri-urban village and its ongoing structural and spatial transformations are representative to the villages throughout Bangladesh. *Choighoria* has a population over 4100 and the number of households is 430. Historically the population of the study village lived on agriculture. Currently, almost 83% people are directly engaged with agricultural food production. The area of total agricultural land is 160 acres and the homestead land are around 40 acres. The village was chosen on the ground that it has enough potential for non-exhaustive sources of energy, available in the form of solar, biomass, as well as rain water. Besides, the population density per acre is 9, indicating that the land's openness is appropriate for the integration of RE and safe water technologies in this settlement.

By applying qualitative case study approach, face to face interviews on semi-structured questionnaire were conducted from February to collect the social data. To collect the spatial data, direct observation and face to face interviews were conducted to understand the existing spatial patterns of the energy sources and water security. The target group for collecting data includes both young and middle age men and women, who are actively engaged in using these energy sources. Random sampling was used to collect information. A total of 35 respondents were randomly selected, among whom 20 respondents are female and 15 are male. Two homesteads are selected to explore the spatial morphology. Large one has arable land and pond adjacent to the homestead where other homestead is compact without having any agricultural land.

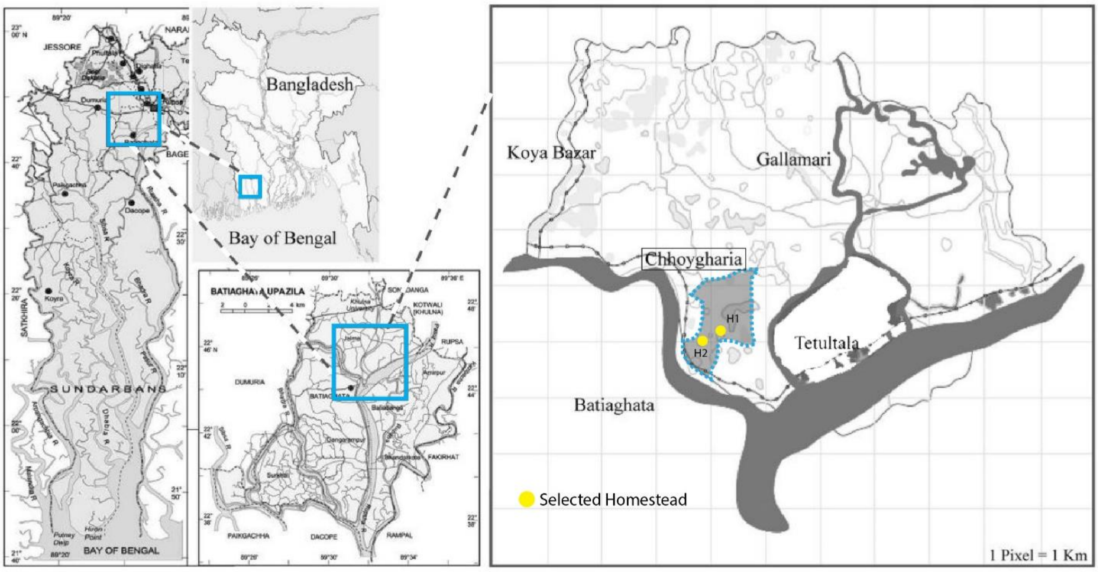

Figure 2. Location map of *Choighoria* villages in Bangladesh, extracted from google map.

Khulna University Studies Special Issue (ICSTEM4IR): 993-1006:2022
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Results

Existing energy status and water security

To investigate the existing energy status at *Choighoria* village, the study is conducted on power (electricity), heating and water security in this village. To identify the actual scenario of the study area, the homesteads in this village are divided into two categories: homestead with arable land and homestead with non-arable land. Initially, this study investigates the consumption, needs and affordability of electricity. During survey, it is found that the sources of electricity are Palli Bidyut, diesel power generation and only a few Solar PV off grid system and their shares in energy supply are approximately 85%, 10% and 5%, respectively (Figure 3). Palli Bidyut is holding a dominant position in terms of feasibility and availability. The electrical appliances that they use within their homestead includes LED light, fan, refrigerator, rice cookers, TV, water pump motor, blender, water kettle, mobile charger and pump-sprayer aerators. In the context of energy, consumption depends on needs and affordability of the household. In the context of Bangladesh, consumption of electricity fluctuates according to the seasonal variation. During the summer, the average monthly electricity bill for households who have arable land might reach 260 units (approximately 1200 BDT electricity bill) and during winter it might reach 100 units. The homestead with non-arable land have consume the average monthly unit during summer is 150 units (approximately 675 BDT electricity bill) and during winter it might reach 80 units. To understand the need of the electricity, the monthly highest payment of electricity bill per household in encountered during the survey. It is found that the highest average monthly bill occasionally exceeds 20% (especially during the time of irrigation and aeration) of the actual monthly consumption, which indicates the actual energy need scenario of the households. However, affordability of electricity depends on household's monthly income. As the World Bank defines affordable electricity that costs no more than 5% of a household's income (Kojima, 2016). According to the statement of World Bank, during survey, it is found that the average monthly electricity cost is 8.5% of household's income which indicates that affordable electricity is the prime need for this community.

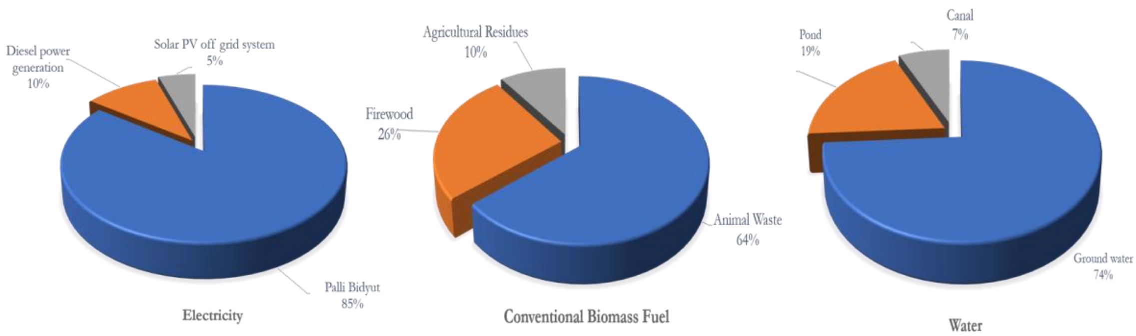

Figure 3. Monthly average consumption of energy and water in *Choighoria* village.

In Bangladesh, the majority of the energy consumed is mainly used for cooking, which accounts for a significant portion of the country's total energy consumption. The social data from the selected case study area also demonstrate the existence of abundant conventional biomass as a source of energy. The major sources of traditional biomass in this settlement are animal dung, firewood and agricultural residues and their shares in energy supply are approximately 64%, 26% and 10%, respectively (Figure 3). It is also found that a substantial amount of fuel is coming from the homestead if self. Particularly, domestic cooking in this settlement represents the largest single consumer of these traditional biomass. Among these sources, animal waste, especially dried dung, is holding the dominant position in terms of its availability as a result of livestock farming attached to homesteads and monthly average consumption per household. However, the amount of dried dung production mostly depends on the types of animals reared on the farm. In this settlement, a substantial amount of dried dung is generated from the manure of cattle. The average number of cattle owned by a household having arable land with their homestead is 6 and the non-arable land is 4. The quantity of dung produced per cattle is 5 to 10 kg per day. However, the amount of dried dung consumption depends on the average household member and the number of cattle in farm. Approximately 20 to 25 dried dung (4 dried dung = 1kg) is used for cooking three meals per day for an average household of seven and 10 to 12 for an average household of five. Though conventional biomass is available in this settlement, the amount of biomass produced on the homestead meets the need for fuel. Besides, the household having homestead with arable land also sell their surplus flues for additional income. However, households without arable land have to purchase a small amount of dried dung (20%) and firewood (5%) for fuel. However, affordability of biomass depends on the availability of land and the financial condition of the household. Though dried dung is the dominant form of fuel here so its affordability depends on the number of cattle, the amount of feeding material and the amount of dung that the cattle produce. Majority of the household revealed that the cost of feeding material sometimes exceeds their affordably level. Besides, to produce the dried dung stick they have to buy the jute stick from local market. On top of that, majority claimed that the production of dried dung is quite labor intensive and consumes a large amount of cooking time. They also revealed that these conventional fuels also create the indoor air pollution by pollutant released inside the kitchen which also support the caution of Khanna (2020), "Exposure to indoor air pollution due to biomass fuel poses a significant health hazard, including pneumonia, tuberculosis, chronic obstructive lung disease, perinatal mortality, and cataract, especially to women and children in the developing world".

Choighoria settlement relies entirely on natural sources of water for their daily activities such as ponds, canal and ground water. However, the monthly consumption of these water services is around 74% for ground water, 19% for ponds, and 10% for canal, respectively (Figure 3). Because of seasonal variations, water is not always available from these sources. The average per-day household consumption of water is around 700 litres for homestead with arable land and 550 litres for homestead with arable land, with ground water accounting for the largest share of this. One of the crucial issues in this region is salinity intrusion, which occasionally restricts the utilization of both deep and shallow tube wells (Shaibur, 2021). Due to minimize the effects of salinization, hand-pump tube wells that draw from the ground water are an important source of domestic water in this village. According to the majority of respondents in this settlement, 450 feet is the average depth of tube wells used to minimize the salinity of water. Majority of the villagers are dependent heavily on this water source for their daily domestic activities such as drinking, cooking, washing, bathing and also farming purposes. As a result, this high dependence level on ground water is gradually transforming the conventional water driving technique from hand pump to electric water pump due to groundwater depletion. Furthermore, during the rainy season, rain water is collected as surface water to restore the pond for fish farming purposes, which is further adversely affected by salinization from nearby saline soils. In addition, this stagnant water is also used for livestock, bathing, and cleaning during and shortly after the rainy season, before they dry out. Another major source of water is the canal which is connected to the Rupsha river through the switch gate. The water of this canal, when available is occasionally used for the irrigation of the agricultural land as well as for fish farming purposes.

Existing spatial-morphological pattern

To understand the existing spatial patterns of energy sources and water services, the orientation, relative positioning, functional linkage and space requirements have been observed. Besides, to identify the actual spatial dynamics of the study area, the two homesteads from this village are taken as cases based on nature of land use: one is homestead with arable land (33375 sq-ft) and the other is homestead with no-arable land (7073 sq-ft.). farming pond, subject to the internal built and natural setting of the homestead, have been observed.

The homestead with arable land (33375 sq-ft.) shows that it is east-west elongated. In case of electricity supply, the homestead is attached with an electricity pole adjacent to it from where the electricity is obtaining. However, the efficiency of the use of space and the productivity of work depends on the area of illumination. According to that, the intensity of light and the space ratio in the homestead are not efficient enough to do the household work effectively. The average size of the rooms in this homestead is 150 sq-ft, and the average use of LED light per room is just 5 watts, which always produces a dismal and unpleasant environment inside the room. Beside there is a strong spatial and functional connectivity required among the cattle shed, fuel shed, kitchen and the pond of the homestead. The placement of the fuel shed adjacent to the cow shed, as well as the east-west elongated orientation of these two shades, indicates an effective spatial arrangement in the overall zoning of the homestead (Figure 4). Due to this orientation, the cattle shade absorbs the maximum heat and light from the west, which helps to eliminate the dampness of the house. Furthermore, this shade collects southern air flow, which facilitate in the elimination of manure odors as well as the reduction of electricity costs. Again, the close proximity between the cattle shed, fuel shed, and the pond also facilitates those household members who are actively involved with the production of dried dung (with the assistance of water) and the cleaning of cattle house.

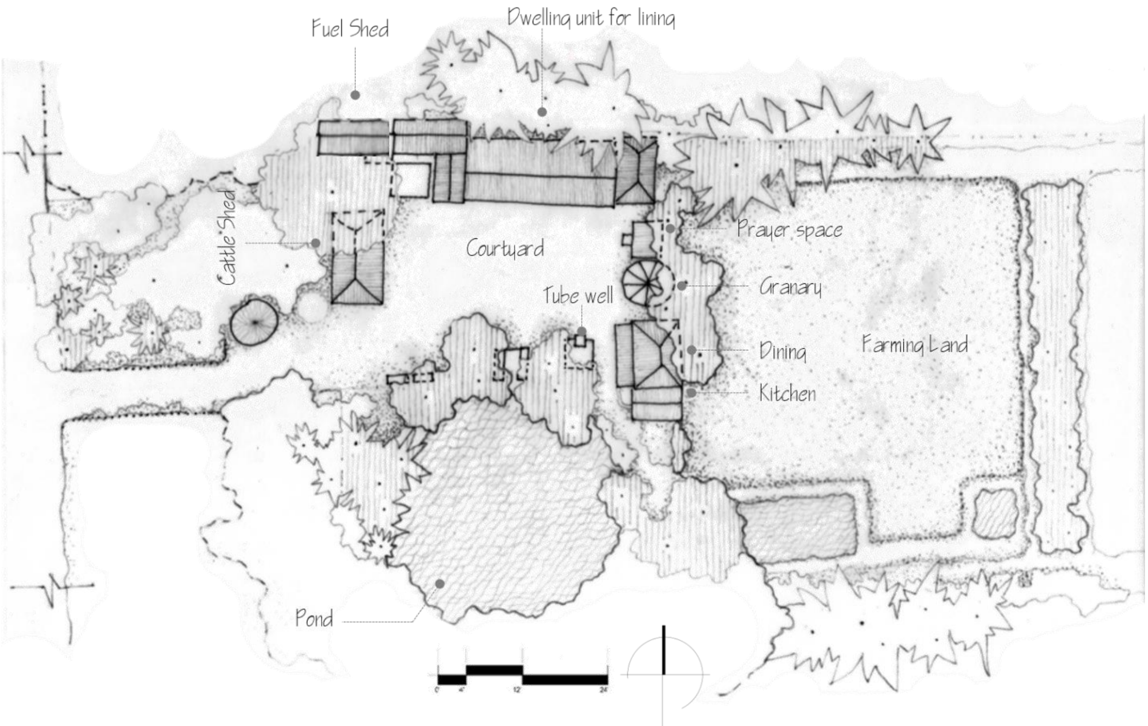

Figure 4. Existing energy and water sources of homestead 1.

However, the placement of kitchen far from the cattle and fuel shade make this spatial connectivity quite inefficient. Because of the regular washing activity, the kitchen is spatially well connected with the pond, but the women have to take long distance to collect the fuel. To ensure the efficient use of water in space, the location of the tube well is always kept near the kitchen and pond so that the waste water from the tube well can runoff into the pond for additional uses, which include fishing, bathing and cleaning of cattle, dish washing, etc.

The homestead with non-arable land (7073 sq-ft.) shows that it is north-south elongated. In case of power, the homestead is connected to an electrical pole adjacent to it, through which the electricity is received. Here, the living room is north-south orientated to receive all the climatic benefits of the location. But, the average size of the room in this homestead is 120 sq-ft, and the average use of LED light per room is just 5 watts, which always produces an inefficient working environment inside the room. However, the spatial and functional connectivity between the kitchen and the cattle shed is comparatively weak (Figure 5). Along with this, the cow shed is positioned on the south side, where the smell of manure reaches the homestead through the southern airflow. Due to lack of space, the fuels are stored within the cattle shade. However, the combustion rate of the fuel often decreased due to the inappropriate orientation of the cattle shade. In addition, due to lack of space, pond is absent in this homestead. So deep tube well is used as a main source of water. Because of the regular washing activity, the kitchen is spatially well connected with the area of tube well but the long distance between the tube well and the cattle shed always decrease the efficiency of work related to cattle shed and production of fuel.

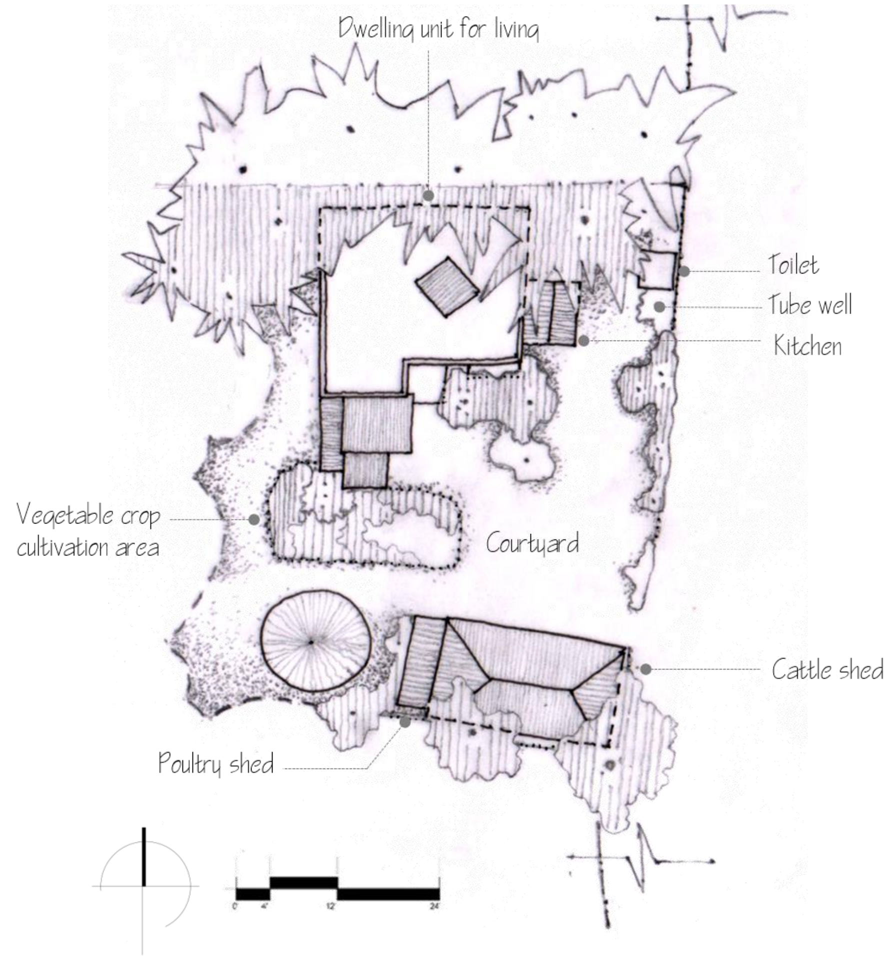

Figure 5. Existing energy and water sources of homestead 2.

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Integrating RE and safe water with rural homestead

In view of the dispersion nature of localities and the low demand of energy and water, decentralized and standalone systems could effectively become a viable option in the remote areas of Bangladesh (Wazed et al. 2008). According to that statement, the existing energy scenario and the spatial pattern of the study area depicts that RE technologies and rain water harvesting system (RWHS) would be an effective solution for sustainable rural transformation. In this study, four indicators are considered such as relative positioning, orientation, effective use of space and functional connectivity to integrate these technologies with rural homestead efficiently.

In case of homestead with arable land, it is found that the area of the homestead which is 33375 sq-ft is sufficient to install all the RE technologies. In case of solar PV system, the east- west elongation of the site as well as the main dwelling unit permits the collection of the maximum solar radiation during the day time. The daily average need of electricity of this homestead is around 4 kWh/day. To satisfy the daily average electricity demand of 4 kWh, 80 panels (100 watts per panel) are required. To install these panels the effective required shaded free space is 320 sq-ft. However, the shaded free roof area of the south facing living space is 577 sq-ft, which is sufficient to install this number of 100-watt panels. The openness of the homestead also supports required space for both the bio gas and rain water harvesting plant. In the case of biogas production plant, efficient spatial zoning is required by placing the kitchen, cattle shed, fuel shed, and pond in close proximity (Figure 6). A 100 cft plant is sufficient to fulfill the daily average need of a household and the required quantity of dung is 75 kg per day. The potential rooftop (catchment) to collect rainwater is the shed of living space due to its large catchment area when planning an efficient rainwater harvesting system. However, the average capacity of a tank depends of the consumption per capita per day, number of people per household and the longest average dry period. According to that for the monthly average consumption of 700 litres water, the capacity of the tank should be 3600 litres and the effective catchment area of rain water is 430 sq ft. To avoid contamination of water sources and to collect the rain water effectively, the placement of RWHS should be relatively high and at a corner of the dwelling unit.

In case of homestead with non-arable land, it is also found that the area of the homestead which is 7073 sq-ft. relatively compact for the installation of all RE technologies. In case of solar PV system, the main dwelling unit permits the collection of the maximum solar radiation due to its south facing orientation during the day time. The daily average need of electricity of this homestead is around 2 kWh/day. To satisfy the daily average electricity demand of 2 kWh, 40 panels (100 watts per panel) are required. To install these panels the effective required shaded free space is 160 sq-ft. However, the shaded free roof area of the south-facing living space is 350 sq-ft, which is sufficient to install this number of 100-watt panels. In the case of biogas production plant, efficient spatial zoning is required by placing the kitchen and cattle shed in close proximity (Figure 7). A 100 cft plant is sufficient to fulfil the daily average need of a household and the required quantity of dung is 75 kg per day. To plan an efficient rainwater harvesting system, the potential rooftop (catchment) to collect rainwater is the shed of living space due to its large catchment area. For the monthly average consumption of 550 litres water, the capacity of the tank should be 2400 litres. In addition, the effective catchment area of rain water is found approximately 700 sq-ft. which is quite efficient to collected the rain water during monsoon season.

Discussion

Findings from the case study reveal that in the case of electricity, Palli Bidyut is holding a dominant position in terms of feasibility and availability among the other sources. However, the consumption of electricity fluctuates according to the seasonal variation, and for households who have arable land, the average monthly electricity bill might reach 260 units during summer. It is found that the highest average monthly bill occasionally exceeds 20% (especially during the time of irrigation and aeration), which indicates the actual

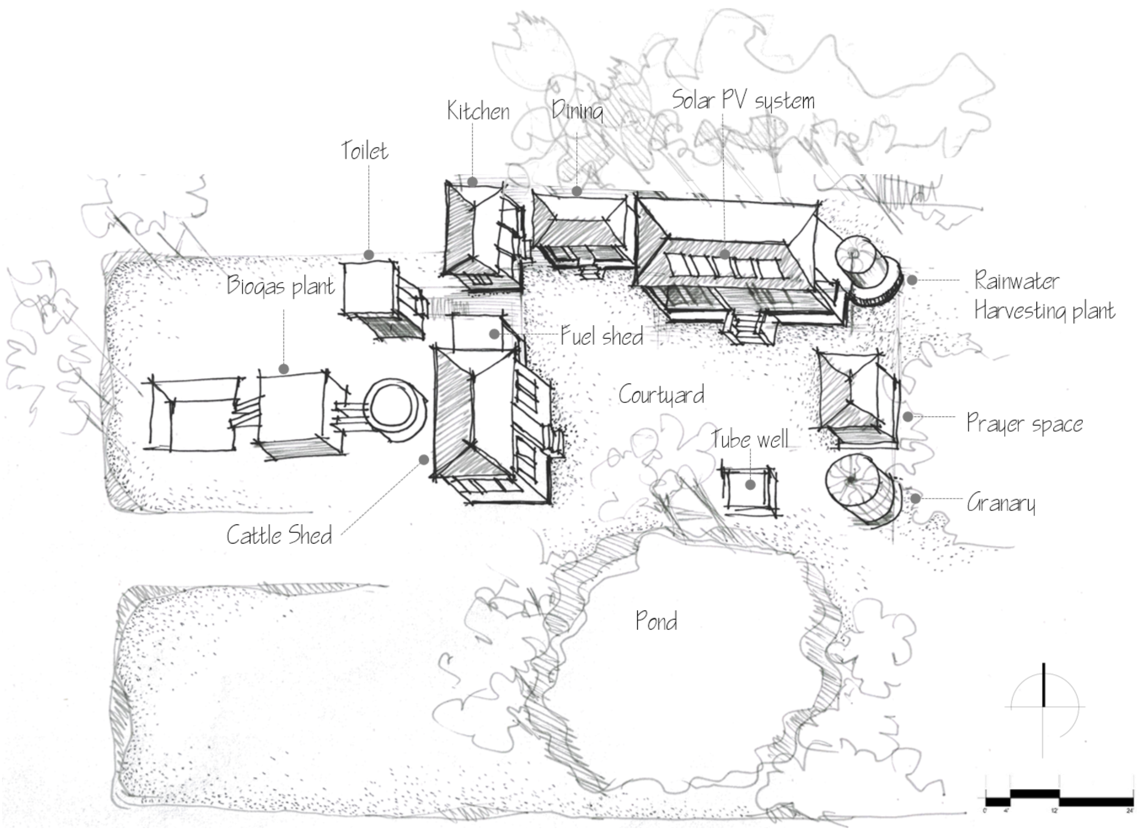

Figure 6. Proposed RE and Safe water Integrated spatial model for homestead 1.

energy need scenario of the households. The study also reveals that the average monthly electricity cost is 8.5% of household's income which indicates that affordable electricity is the prime need for this community. In case of biomass, it is found that a substantial amount of fuel is coming from the homestead if self. Particularly, domestic cooking in this settlement represents the largest single consumer of these traditional biomass. Among the sources of biomass, dried dung is holding the dominant position in terms of its availability. Though conventional biomass is available in this settlement especially cow dung, the amount of biomass produced on the homestead meets the need for fuel. Though dried dung is the dominant form of fuel here so its affordability depends on the number of cattle, the amount of feeding material and the amount of dung that the cattle produce. Furthermore, *Choighoria* settlement relies entirely on ground water (74%) for their daily domestic activities like drinking, cooking, washing, bathing and also farming purposes. The average per-day household consumption of water is around 700 litres for household who have arable land and 550 litres for household who don't have any arable land, with ground water accounting for the largest share of this. The study reveals that the reason for using ground water is salinity instruction, and this high dependence level on ground water is gradually transforming the conventional water driving technique from hand pump to electric water pump due to groundwater depletion.

To understand the existing spatial patterns of energy sources and water services the position, orientation, functional linkage and space requirements have been observed. Besides, to identify the actual spatial dynamics of the study area, the two homesteads from this village are taken as cases. The homestead with arable land (33375 sq-ft.) shows that it is east-west elongated. the homestead is attached with an electricity

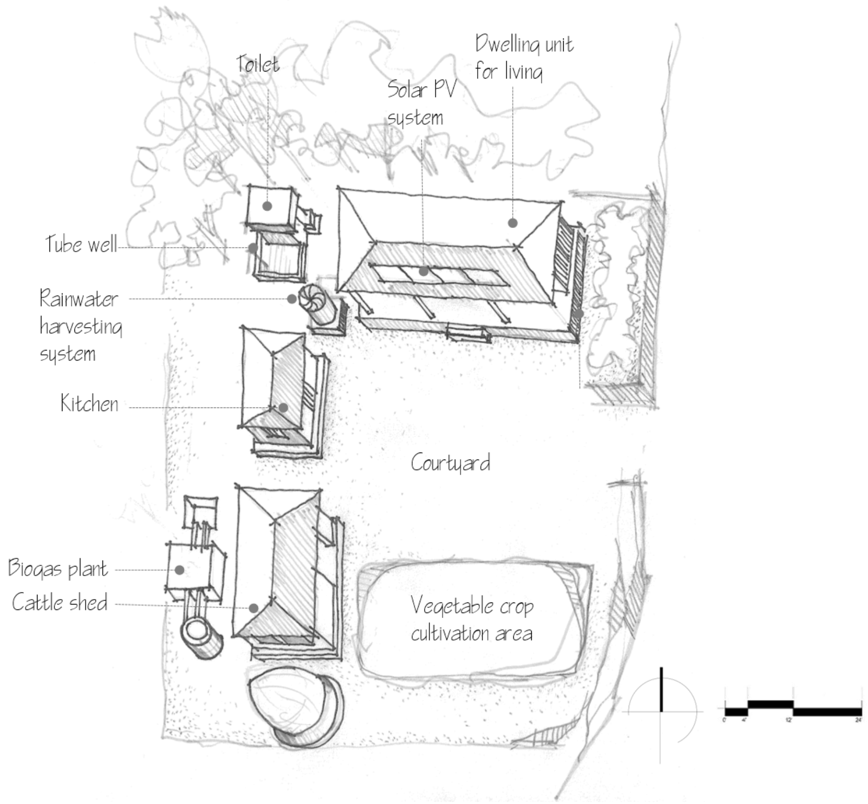

Figure 7. Proposed RE and Safe water Integrated spatial model for homestead 2.

pole adjacent to it. In case of electricity, the findings from the spatial analysis reveal that the intensity of light and the space ratio in the homestead are not efficient enough to do the household work effectively. Beside there is a strong functional and spatial connectivity is required between the cattle shed, fuel shed, kitchen and the pond of the homestead. The placement of the cow shed adjacent to the fuel shed and the pond along with their orientation indicates an effective spatial arrangement in the overall zoning of the homestead. However, the placement of kitchen far from the cattle and fuel shade make this spatial and functional connectivity quite inefficient. Additionally, to ensure the efficient use of water in space, the location of the tube well is always kept near the kitchen and pond so that the waste water from the tube well can runoff into the pond for additional uses which including fishing, bathing and cleaning of cattle, dish washing etc. Another homestead is north-south elongated. In case of power, the homestead is connected to an electrical pole adjacent to it. Here, the living room is north-south orientated to receive all the climatic benefits of the location. However, the intensity of light and the space ratio in the homestead produce an inefficient working environment inside the room. Besides, the spatial and functional connectivity between the kitchen and the cattle shed is comparatively weak. Along with this, the inappropriate orientation of the cattle shade and its weak spatial connectivity with the tube well always decrease the efficiency of work related to the cattle shed and the production of fuel.
These findings have underpinned the design considerations that include:

- In case of solar PV system, the east- west elongation of the homestead as well as the south facing dwelling unit (living room) permits the collection of the maximum solar radiation during the day time. According to the need of electricity, the roof area of the main dwelling unit (living space) is relatively sufficient for the effective shaded free space required to install solar panels.

- The openness of the homestead also supports required space for the installation of bio gas plant. Efficient spatial zoning is required while designing a biogas plant by placing the kitchen, cattle shed, fuel shed, and pond in close proximity. Where the pond is not be available, the tube well will be placed in the close proximity of the biogas plant for the proper mixture of water and feeding materials.
- The potential rooftop (catchment) to collect rainwater is the shed of living space due to its large catchment area and orientation when planning an efficient rainwater harvesting system. However, the average capacity of a tank depends of the consumption per capita per day, number of people per household and longest average dry period. According to the consumption of water and capacity of the tank, the roof area of the dwelling unit is sufficient to collect the required amount of rain water during monsoon season. To avoid contamination of water sources and to collect the rain water effectively, the placement of RWHS should be relatively high and at a corner of the dwelling unit.

Conclusion

The proposed model delineates how integrating small-scale multiple systems of renewable energy and safe water at homestead level can be small but effective and sustainable solution towards addressing the big problem of energy crisis in vast rural areas of Bangladesh. Regarding the RE-focused policies and initiatives of the government, decentralized energy production should be encouraged where homestead is the best physical-spatial entity to be the basic unit for installation of RE systems. Research in similar geo-climatic context reveals that, the small-scale power generation systems based on the renewable energy sources are more efficient and cost effective (Hiremath, 2009). Thus, focus should be on the small-scale renewable energy and safe water technologies that can be implemented locally by communities and small-scale producers, but can make a significant overall contribution towards the national energy and water supply. To this end, the RE and Safe Water-Integrated spatial model proposed in this research can provide policy direction towards people-place-technology and environment friendly solutions to meet the energy and water needs of the rural areas.

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