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Agroecological, Land-Elevation and Socioeconomic Determinants of Raising Livestock in Bangladesh

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Abstract: This paper determines the influence of agroecological, land-elevation and socioeconomic factors in the raising of different types of livestock in Bangladesh using nationwide sub-district level data from two Agriculture and Livestock Censuses of 1996 and 2008, by applying a simultaneous equations model. Results reveal that socioeconomic, land-elevation and agroecological factors exert significant but varied influence on the type of livestock raised by householders. The number of cattle, goat/sheep and poultry raised per household are significantly higher for medium and small farms as well as for wage-labour households. Cattle raised per household is significantly higher for non-farm households, whereas poultry raised is significantly lower. Gross-cropped area, literacy rate and research and development (R&D) investment significantly influence the number of cattle raised per household, whereas population density negatively influences the number of goat and poultry raised per household. The number of cattle and goat/sheep raised per household is significantly higher in the Old Himalayan Floodplain, whereas poultry-raising is significantly higher in the Eastern Hills and seven other agroecologies. Raising all types of livestock is significantly lower in low-lying areas. The number of cattle raised per household is significantly higher at high land elevation, but significantly lower in medium-low land and low-lying areas. On the other hand, the number of goat/sheep and poultry raised per household is significantly higher in medium-high land areas and significantly lower in low-lying areas. The policy implications of these results will be relevant to investments in R&D, education, tenurial reform and measures to promote different types of livestock suited to specific agroecology and land-elevation levels.

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1. Introduction

Rising populations, income and urbanization in developing countries are increasing the demand for food from animal origin at unprecedented levels [1]. The increasing demand for milk, meat and eggs are the major driving force for these changes [2]. Livestock products are important for global food security because they provide 17% of global calorie consumption and 33% of global protein consumption [3]. Livestock possesses tremendous opportunities for poverty reduction, and the sector provides livelihood support for 1 billion of the world's poorest people and employs 1.1 billion people [4]. The rapid growth in demand for livestock products, particularly in developing economies, is termed the 'livestock revolution' [5,6]. Global milk production is projected to increase from 664 million tons in 2006 to 1077 million tons in 2050, and meat production to double from 258 million tons to 455 million tons [7].

Herrero et al. [8] noted that although the largest number of livestock populations are found in the tropics and sub-tropics agroecological zones, especially in arid and semi-arid regions of the world, productivity is highest in temperate regions. Although the livestock sector itself is considered to be a

contributor to climate change, mainly through greenhouse gas (GHG) emissions, the sector itself is also under threat from climate change. For example, the livestock sector contributes 14.5% of global GHG emissions, but increased production of the sector will be limited by climate variability because animal water consumption will need to increase threefold and the demand for agricultural land by 70% to meet these needs [9].

In fact, mixed crop/livestock systems provide the majority of livestock and food crop products in developing countries [10]. An estimated 1 billion head of livestock is raised by 600 million farmers in the rural regions of the developing world [11]. Some countries are already promoting intensification of livestock management as a policy response to meet increasing demand for milk, meat and eggs [12]. However, deriving benefits from the intensification of livestock remains a major challenge for smallholders [10].

Livestock is an integral component of the complex farming system and socioeconomic life of the rural population in India, Nepal and Bangladesh [13–15]. The livestock sector contributes significantly towards employment in Bangladesh, providing full time employment for 20% of the total population and part-time employment for another 50% of the total population [16]. Its contribution to national income, however, is modest and is in the region of 2.6% per annum during the 1990s [17]. However, the growth rate of this sector is much higher, estimated at 5.0% per annum during the period 1991–2006 as compared to the agricultural growth rate of only 2.6% per annum for the same period [15]. The sector is also an important source of meat protein. Poultry meat alone contributes a substantial 37% of total meat production in Bangladesh [16].

Realizing the importance of the livestock sector in the economy, the government of Bangladesh launched a comprehensive National Livestock Policy in 2005 with two distinct objectives: (a) to ensure the supply of adequate livestock and livestock products for human consumption; and (b) to increase the supply of animal power and animal waste for crop production and product processing [18]. Also, all of the successive six five-year plans of Bangladesh covering the period 1975–2015 emphasized development of the livestock sector, with a tripartite objective of increasing farm-power services, sources of animal protein for its population, and generating employment in rural areas [15].

However, despite the government's thrust, the growth of livestock sector in Bangladesh is not very encouraging. Rahman et al. [15] noted variable rates of growth of livestock over time with a relatively higher rate of increase for the poultry population. For example, the cattle population, which has been the main source of draft power services in the Bangladeshi farming system until recently, increased by only 0.09% and 1.47% per year between the Agriculture and Livestock Censuses of 1984, 1996 and 2008. On the other hand, the corresponding increase in poultry population was 5.99% per year between 1984 and 1996, but which then fell to only 0.70% per year between 1996 and 2008 [15]. Nevertheless, per capita livestock increased slightly with wide regional variation with respect to growth and distribution over time [15].

It is generally recognized that the type of livestock raised by household producers varies across agroecological conditions and regions of the world, and is influenced by tradition/culture, family life cycle, resources and wealth [19,20]. In addition, advocates of the intensification of livestock production to meet the increasing demand for livestock and its products, as well as to improve livelihoods of the poor, have noted that householders' response to intensification depends on the availability of resources, family situation and livelihood alternatives [12].

Therefore, given the slow growth of livestock and livestock products over time despite the government's efforts to promote this sector, the present study is aimed at identifying the drivers of raising livestock by the householders in Bangladesh. We do this by using sub-district level information from two Agriculture and Livestock Censuses of 1996 and 2008. The main contribution of this study to existing literature is that we have empirically examined the magnitude and direction of the influence of a range of socioeconomic, land elevation and agroecological factors on raising livestock for an average householder at the sub-district level in Bangladesh in a way that is nationally representative and with results capable of being generalized for a wider context.

The paper is structured as follows. Section 2 presents the methodology, data and variables. Section 3 presents the results. Section 4 concludes and draws policy implications.

2. Methodology

2.1. The Theoretical Model

We base our analytical framework on a general model of farm production to examine the factors influencing livestock-raising at the household level [21,22]. The farm household produces a vector *Q* of outputs from livestock using a vector of inputs *X*. The decision of choice, however, is constrained by a given production technology that allows a combination of inputs (*X*) among *j* categories of livestock, given the characteristics of the farm (*Z*). The total output of each household *i* is given by a stochastic quasi-concave production function:

$$Q_{ij} = f(X_{ijk} \ldots X_{ijk}, \varepsilon | Z_i) \tag{1}$$

where ε is random noise. It is assumed that $f_{Xk} > 0$ and $f_{XXk} < 0$. The number of each type of livestock raised implies the level of outputs. The profit of each farm *i* is given by:

$$\pi_i(Q, X, p, w | Z_i) = \sum_{j=1}^{J} p_j Q_{ij} - \sum_{k=1}^{K} w_j X_{ijk} \tag{2}$$

where *p* is the vector of output prices and *w* is the vector of input prices.

The household is assumed to have a von Neuman–Morgenstern utility function, $U(W)$ defined on wealth *W* with $U_W > 0$ and $U_{WW} < 0$. The wealth is represented by the sum of initial wealth (W_0) and the profit generated from raising livestock (π). Therefore, the objective of each household is to maximize expected utility as [23]:

$$EU(W_0 + \pi(Q, X, p, w | Z_i) \tag{3}$$

where *E* is the expectation operator defined over ε; *Q* is the vector of output from livestock; *X* is the vector of inputs; *p* is the vector of output prices; *w* is the vector of input prices; and *Z* is the level of fixed factors. The choice variables in (1), the household's input levels X_{ijk}, are given by the first-order conditions

$$\frac{\partial EU}{\partial X_{ijk}} = EU_w(p_j \times f_{Mijk} - w_k) = 0 \tag{4}$$

The second-order conditions are satisfied under risk aversion and a quasi-concave production function (Isik 2004). The optimal input mix is given by:

$$X_{ijk}^* = X_{ijk}^*(p_j, w_k, U | Z_i) \tag{5}$$

The optimal output mix, depending on (X_{ijk}^*) is defined as:

$$Q_{ij}^* = f(X_{ij1}^*, \ldots \ldots X_{ijk}^*) | Z_i) \tag{6}$$

2.2. Determinants of the Choice of Raising Livestock

To determine the factors affecting a household's choice of livestock, we derive the equivalent wealth or income from the expected utility [21,22]:

$$E_i = E(W_0 + \pi_i(Q, X, p, w | Z_i) \tag{7}$$

This equivalent wealth or income in a single decision-making period is composed of net earnings (profits) from raising livestock and initial wealth that is 'exogenous' to livestock choices (W_0), such as capital assets carried over from an earlier period.

Under the assumption of a perfect market, livestock production decisions are made separately from consumption decisions and the household maximizes net earnings (profits) subject to its technology and expenditure constraints [24]. However, a household's production and consumption decision cannot be separated if there are imperfections in the market for labour and other inputs, and in such case the prices becomes endogenous to the household and are influenced by market transaction costs [24]. When a household's production and consumption decisions cannot be separated, the household's optimal choice can be expressed as a reduced form function of the household's socioeconomic characteristics and initial wealth or income [24]:

$$h_i^* = h_i^*(Z_i, W_{0i}) \tag{8}$$

Equation (8) forms the basis for econometric estimation to examine the factors influencing livestock-raising by the individual household, an outcome of choices made in a constrained optimization problem.

After developing the model for an individual household, we extend the model to a typical household at the sub-district level [22]. The key assumption is that the factors affecting the choice of raising livestock at the individual farm/household level in a given period can be applied to identify the determinants of raising livestock for an average householder at the sub-district level (which, essentially, represents an individual household's response residing in a sub-district):

$$L_{rj} = L_{rj}(Z_r, W_{0r}) \tag{9}$$

2.3. Data and Variables

Principal data on livestock resources and selected socioeconomic indicators were taken from two censuses of agriculture and livestock in Bangladesh 1996 and 2008 [25,26]. The raw data includes *upazila* (sub-district) level information from all of the 62 districts of Bangladesh for both census periods (which was available at the Bangladesh Bureau of Statistics (BBS) website). A total of 501 sub-districts were identified in the census year 1996, and 528 sub-districts in the census year 2008, thereby providing a total of 1029 observations. The increase in the number of sub-districts in 2008 is due to the formation of new sub-districts derived from the older and larger sub-districts. Additional socioeconomic information at the corresponding sub-district level for all of the 62 districts was taken from the Community Level Reports of the Population Censuses of 2001 and 2011 [27].

The dependent variables are the total number of three main types of livestock raised per household covered in the Agriculture and Livestock Censuses. The categories are: (a) cattle; (b) goat/sheep; and (c) poultry. Independent variables are operational measurements of the vectors shown on the right-hand side of Equation (9). A wide range of variables was incorporated representing agroecological and socioeconomic factors. These are: household categories, gross cropped area (GCA), irrigated area, homestead area, subsistence pressure (measured by household size), population density, literacy rate, and research and development (R&D) investment in livestock and agroecological zones (AEZ). The various variables are defined and constructed as follows (Table 1):

Table 1. List and definition of variables used in the econometric model.

Variable Name	Definition and Construction Details
Livestock types	Three dependent variables were identified: (1) cattle, defined as the total number of cattle and buffaloes per household; (2) goat/sheep, defined as the total number of goat and sheep per household (the census reports both the number of goat and sheep as one category. Also, goat is the dominant animal in Bangladesh); and (3) poultry, defined as the total number of fowl per household in each sub-district for the years 1996 and 2008, respectively.
Non-farm households	Proportion of non-farm households in each sub-district for the years 1996 and 2008, respectively.
Small farms	Proportion of small farms (owning land between 0.02 and 1.00 ha) in each sub-district for the years 1996 and 2008, respectively.
Medium farms	Proportion of medium-sized farms (owning land between 1.01 and 3.03 ha) in each sub-district for the years 1996 and 2008, respectively.
Large farms	Proportion of large farms (owning land >3.03 ha) in each sub-district for the years 1996 and 2008, respectively.
Labour households	Proportion of households surviving on selling labour only in each sub-district for the years 1996 and 2008, respectively.
Gross cropped area (GCA) per household	Amount of cultivated land (ha) per household in each sub-district for the years 1996 and 2008, respectively.
Irrigated area per household	Amount of irrigated area (ha) per household in each sub-district for the years 1996 and 2008, respectively.
Homestead area per household	Amount of homestead area (ha) per household in each sub-district for the years 1996 and 2008, respectively.
Owned land per household	Amount of total land owned (ha) per household in each sub-district for the years 1996 and 2008, respectively.
Average literacy rate	Average literacy rate of population aged 7 years and above in each sub-district for the years 2001 and 2011, respectively. These data are taken from Population Censuses of 2001 and 2011, respectively. In absence of any matching years between the two types of censuses, we have matched the Population Census data of 2001 with Agriculture and Livestock Census data of 1996 and Population Census data of 2011 with Agriculture and Livestock Census data of 2008 for the same sub-district. We consider that using exact census information is more accurate than applying inter-census linear interpolation technique to match exact years for both sets of data.
Population density	Population density per sq. km in the rural areas in each sub-district for the years 2001 and 2011 which were taken from the Population Censuses of 2001 and 2011, respectively,
Research and development (R&D) expenditure	Research and Development (R&D) expenditure data specifically for livestock (from the time it is available) is converted to a series involving a time-lag in order to take account of the time required for the technology generated by the research system to reach the farmers. In order to take the lag into account, the weighted sum of research expenditures over a period of 14 years is used. The research variable is constructed as $\sum W_{t-i} R_{t-i}$, where W_i is a weight and R_{t-i} is research investment in year $t - i$ measured at constant 1996 prices. The weight for the census-year research expenditure is zero, for a one-year lag the weight is 0.2, while for a two-year lag it is 0.4, and so on [28]. This is a national-level figure only.
Land elevation	The Bangladesh Agricultural Research Council (BARC) created a database of area (ha) of major land-elevation types in each sub-district and for 30 AEZs [29]. The land-elevation data in Bangladesh is classified according to flooding depth of the landscape. These are: High Land (i.e., no flooding); Medium-High Land (flooding depth of 0.10–0.90 m); Medium-Low Land (flooding depth of 0.91–1.83 m); Low Land (flooding depth of >1.83 m). We have used this sub-district level information and constructed a complete set of the proportion of High Land, Medium-High Land, Medium-Low Land, and Low Land for each sub-district [29].
Agroecology	Bangladesh consists of 30 agroecological zones (AEZ) constructed jointly by UNDP and FAO in 1988 which overlaps amongst administrative boundaries, thereby, making regional classification very difficult [30]. However, Quddus [31] conducted an exercise by combining two or three AEZs together so that the new classification commensurate with district administrative boundaries. The result was 12 AEZs derived from original 30 AEZs that can be distributed into 64 new districts and are mutually exclusive [31]. We have created a set of 12 dummy variables representing these new 12 composite AEZs and allocated them to individual sub-districts located within 62 districts as appropriate.

The choice of these variables is largely based on the literature examining determinants of raising livestock at the farm level [14,32]. In addition, the choice is limited by data availability at the level of disaggregation required for this study, i.e., the sub-district level, so that the results are representative and generalizable to a wider context. In a mixed crop/livestock system, which dominates in Bangladesh, the area under crop production is expected to have an influence on the amount of livestock raised, as it is one of the typical farm characteristics that influences decision-making [19,20]. In addition, cattle are the main source of farm power services in Bangladesh [15]. Therefore, gross cropped area per household was incorporated to identify its influence on raising livestock. Irrigation is included because it is strongly related to the expansion of high-yielding variety (HYV) rice area in Bangladesh [21], which may in turn influence raising livestock to support farm power services. In Bangladesh, land ownership serves as a surrogate for a large number of factors as it is a major source of wealth and influences farm production decisions [21]. Therefore, the amount of owned land per household is included in order to identify its individual influence on raising livestock. The homestead area is included because poultry are traditionally raised at the farmyard or homestead [12]. Family size is included for two reasons. First, according to the Chayanovian theory, higher subsistence pressure (measured by family size) generally leads to the adoption of modern technologies in farming. Second, a large family size may imply supply of more family labour, which may influence raising livestock [22] The education variable was used because it serves as a proxy to access to information as well as capacity to understand the technical aspects and profitability related to livestock production, which may influence livestock-raising decisions [21]. R&D is an important element in disseminating modern technology and production knowhow to farmers, and the potential of agricultural sector growth hinges largely on its effectiveness [22]. Therefore, R&D expenditure specific to the livestock sector was incorporated to account for its influence on raising livestock. Similarly, agroecological characteristics are another important feature that either limit or open up opportunities for farmers to choose their livestock portfolio [19,20]. As such, 11 dummy variables representing agroecological zones were incorporated in the models to identify their independent influence on raising livestock, leaving the remaining 12th AEZ subsumed in the intercept/constant term. Finally, land elevation (measured with respect to flooding depth) is also an important feature that is expected to influence farmers' decisions to raise different types of livestock. Therefore, we have included variables representing proportions of high land, medium-high land, medium-low land, and low, including very low land areas available at the sub-district level to identify their influence on raising livestock. However, because of the coexistence of all four categories of land elevation in each sub-district in variable proportions, the proportion of area under high-land elevation is significantly negatively correlated with the remaining three categories ($r \geq -0.99, p < 0.01$). Therefore, in order to break multicollinearity, we have executed four separate models by replacing one land-elevation category at a time, while retaining all other variables [33].

2.4. The Empirical Model

In order to identify the socioeconomic and agroecological determinants of three types of livestock, we use a simultaneous equations system consisting of three equations. In order to incorporate non-linearity in the model structure, we specified a double-log specification where the parameters are log-linear except for the dummy variables, which are not logged. The three empirical equations, dropping the rth sub-district, are:

$$\ln L_C = \alpha_C + \sum_{i=1}^{8} \alpha_{Ci} \ln Z_{Ci} + \sum_{j=1}^{2} \beta_{Cj} \ln W_{Cj} + \sum_{k=1}^{11} \delta_{Ck} A_{Ck} + \varepsilon_C \tag{10}$$

$$\ln L_G = \alpha_G + \sum_{i=1}^{8} \alpha_{Gi} \ln Z_{Gi} + \sum_{j=1}^{2} \beta_{Gj} \ln W_{Gj} + \sum_{k=1}^{11} \delta_{Gk} A_{Gk} + \varepsilon_G \tag{11}$$

$$\ln L_P \;=\; \alpha_P \;+\; \sum_{i=1}^{8} \alpha_{Pi} \ln Z_{Pi} + \sum_{j=1}^{2} \beta_{Pj} \ln W_{Pj} + \sum_{k=1}^{11} \delta_{Pk} A_{Pk} + \varepsilon_P \tag{12}$$

where L_s represents the dependent variables and the subscripts C, G, and P stand for cattle, goat/sheep, and poultry, respectively; Z_s represents the socio-economic features of the sub-districts; W_s represents the wealth of the average householders of the sub-districts; As are the dummy variables representing agroecological zones; α, β and δ are the parameters to be estimated; ε_s are the error terms; and ln is the natural logarithm.

In order to enable estimation of a linear system of equations, the necessary condition for identification of an individual structural equation in the system is as follows: if $m_i > (K - k_i)$, then the equation is under-identified and cannot be estimated. Here, m_i is the number of endogenous variables in an individual structural equation; k_i is the number of exogenous variables in the same structural equation; and K is the total number of exogenous variables in the system [34]. In our system of structural equations, the value of m_i in each equation is zero, as we did not specify any endogenous variable as regressor in the system. On the other hand, the value of $(K - k_i)$ in the cattle model is two and in the goat/sheep and poultry models three each. Therefore, the identification condition is satisfied and the system as a whole is over-identified and can be estimated.

3. Results

3.1. Distribution of Livestock Numbers and Socioeconomic Features by Agroecological Zones

Since one of the focuses of this study is to highlight the influence of agroecology on raising livestock, we first provide evidence of differences with respect to selected indicators including the number of livestock raised per household among 12 composite AEZs. The United Nations Development Program (UNDP) and Food and Agriculture Organization (FAO) jointly conducted a major analysis to identify the AEZs of Bangladesh, which are based mainly on land types, soil types, fertility, conditions, temperature and rainfall regimes, and identified 30 AEZs [30]. Table 2 presents selected indicators by AEZs for the census year 2008 only, but also provides comparative information for the same indicators between the census years. It is clear from Table 2 that the number of cattle per household has increased only in two AEZs but declined in all other AEZs between the census years. The number of goat/sheep per household has increased in five AEZs but declined in the remaining seven AEZs, while the number of poultry declined in all AEZs in 2008.

The dynamics of farm-size changes in Bangladesh is also clear. The noticeable feature in Table 2 is the increase of non-farm households in all AEZs in 2008 at the expense of a decline in medium- and large-sized farms throughout. In addition, the proportion of small farms has increased only in three AEZs and declined in the remaining AEZs between the census years. In other words, the proportion of farmers of all size categories is actually declining in Bangladesh over time and giving rise to rural residents who are not farmers. Overall, 39.6% of all rural residents are classified as non-farm households and 49.3% are small farmers in the country in 2008. This is quite an unexpected find, as Bangladesh is conventionally understood in the literature as an agrarian economy. Rahman and Rahman [35] also noted that the number of small farms has increased at the expense of medium- and large-sized farms in Bangladesh over time. Also, the amount of gross cropped area per household declined throughout the country in 2008 as compared to 1996, indicating increased pressure to produce more food crops from a lower cultivable land base (Table 2). Rahman and Rahman [35] also noted that not only is the availability of land shrinking, but also another key farm resource endowment, the draft animal, is declining rapidly in Bangladesh. As expected, both rural population density and literacy rate has increased throughout between the census years.

Table 2. Selected indicators of livestock and socioeconomic factors by agroecological zones of Bangladesh.

Agroecological Zones	Year	Cattle Per Household	Goat/Sheep Per Household	Poultry Per Household	Small Farms	Medium Farms	Large Farms	Non-Farm Households	Gross Cropped Area	Population Density	Literacy Rate
Old Himalayan Piedmont Plain and Tista Floodplain	2008	1.510	0.982	5.133	0.480	0.107	0.014	0.398	1.693	981.894	46.477
	1996	1.349	0.972	6.389	0.477	0.138	0.023	0.363	1.962	859.318	39.677
Karatoa Floodplain and Atrai Basin	2008	1.310	0.970	6.657	0.495	0.107	0.014	0.384	1.701	962.019	48.728
	1996	1.147	0.786	6.930	0.494	0.137	0.023	0.345	1.879	855.154	42.785
Brahmaputra–Jamuna Floodplain	2008	0.969	0.428	4.328	0.502	0.086	0.010	0.402	1.303	1076.123	40.971
	1996	1.055	0.502	5.478	0.515	0.113	0.018	0.355	1.642	977.797	36.027
High Ganges River Floodplain	2008	1.103	1.107	5.124	0.532	0.097	0.008	0.363	1.411	1039.623	48.375
	1996	1.175	0.843	6.275	0.508	0.142	0.019	0.331	1.845	937.233	43.347
Low Ganges River Floodplain	2008	0.915	0.675	4.851	0.507	0.099	0.007	0.387	1.172	914.320	51.128
	1996	1.030	0.582	5.101	0.525	0.149	0.016	0.310	1.936	851.680	42.984
Ganges Tidal Floodplain	2008	1.012	0.558	8.106	0.558	0.094	0.011	0.336	1.069	727.959	56.463
	1996	1.168	0.475	8.512	0.575	0.140	0.024	0.262	1.573	676.333	53.145
Sylhet Basin and Surma–Kushiyara Floodplain	2008	1.216	0.303	4.735	0.434	0.115	0.020	0.431	1.139	885.625	43.348
	1996	1.299	0.345	6.108	0.444	0.148	0.034	0.374	1.554	709.703	38.411
Middle Meghna River Floodplain	2008	0.695	0.289	5.796	0.557	0.038	0.002	0.403	0.774	1650.029	51.591
	1996	0.975	0.440	7.973	0.614	0.067	0.004	0.303	1.262	1310.724	42.845
Lower Meghna River and Estuarine Floodplain	2008	0.665	0.303	7.936	0.560	0.060	0.006	0.374	0.969	1396.059	54.265
	1996	0.912	0.349	9.996	0.631	0.080	0.010	0.279	1.382	1189.214	48.279
Chittagong Coastal Plain and St. Martin's Coral Island	2008	0.664	0.286	4.235	0.382	0.037	0.003	0.578	0.575	1142.500	47.954
	1996	1.145	0.416	9.143	0.488	0.097	0.014	0.401	1.277	914.095	42.738
Eastern Hills	2008	1.329	1.001	9.025	0.411	0.314	0.059	0.217	2.155	153.893	42.507
	1996	1.573	0.951	9.558	0.373	0.335	0.058	0.234	2.134	131.714	36.729
Greater Dhaka	2008	0.620	0.353	3.152	0.406	0.045	0.003	0.546	0.631	2382.100	54.815
	1996	0.855	0.471	4.777	0.485	0.079	0.007	0.429	1.068	1515.556	47.672
Bangladesh	2008	1.059	0.656	5.704	0.493	0.099	0.012	0.396	1.268	1079.844	48.691
	1996	1.160	0.634	6.893	0.508	0.136	0.022	0.334	1.674	890.854	42.861
Test for differences across agro ecological zones (Generalized linear model with one way ANOVA)											
$F_{(11,515)}$	2008	2.78 *	6.10 *	25.61 *	17.02 *	84.42 *	62.14 *	26.19 *	28.68 *	19.59 *	22.32 *
	1996	1.29	3.27 *	38.12 *	23.84 *	65.32 *	23.52 *	20.41 *	15.18 *	26.75 *	18.78 *

Note: * significant at 1% level ($p < 0.01$).

Table 2 also shows that the number of livestock raised per household varies significantly across AEZs, which confirms the notion that agroecological conditions have an influence on livestock production [19,20]. The highest number of cattle per household was raised in the Old Himalayan and Tista Floodplains followed by the Eastern Hills and the Karatoa Floodplain and Atrai Basin. The average number of cattle per household in the country was only 1.05 in 2008, a decline from 1.16 in 1996, which is seriously inadequate for supporting farm-power services, explaining the rise of power tillers for conducting farm operations in recent years [15]. The number of goat/sheep per household is even more inadequate, with the highest number raised in the High Ganges River Floodplain followed by the Eastern Hills. The highest number of poultry per household was raised in the Eastern Hills followed by the Ganges Tidal Floodplain and Lower Meghna River Floodplain and Estuaries. Raising a high number of livestock of all types in the Eastern Hills is expected, because this area is characterized by a highly undulated landscape with a concentration of tribal populations who mainly operate *jhum* cultivation (i.e., slash-and-burn agriculture), fruit orchards, grow fewer foodgrain crops, and have the lowest level of population density in the country (Table 2). Significant variation exists with respect to all other indicators across AEZs, with the highest GCA per household in the Eastern Hills followed by the Karatoa Floodplain and Atrai Basin and the Old Himalayan and Tista Floodplains. The overall GCA per household in Bangladesh was only 1.27 ha in 2008, which is slightly higher than the 1.00 ha of cultivated area required to sustain a typical rural family [36].

3.2. Determinants of Raising Livestock

Table 3 presents the results of the range of hypothesis tests conducted to select the appropriate estimation procedure and joint influence of various types of factor on raising livestock at the household level and Table 4 presents the results of the parameter estimates of the system of three structural equations of the livestock raised per household using Equations (10)–(12).

The first consideration is the choice of estimation procedure. The two most common estimation procedure of a simultaneous equations system are the limited information method (known as the two-stage least squares or 2SLS) and full information method (known as the three-stage least squares or 3SLS). The choice of the estimation technique depends on whether the assumptions underlying the two different methods are supported by the data. If all equations in the structural model are correctly specified, the systems estimator (i.e., 3SLS) is more efficient than the single-equation estimator (i.e., 2SLS). However, if one of the equations in the system is mis-specified, then the parameter estimates using 3SLS are inconsistent but 2SLS are consistent. The Hausman specification test was performed to choose the estimation procedure, which indicated that the null hypothesis cannot be rejected, implying that the 3SLS estimator is efficient and, therefore, used to estimate the system of equations (i.e., Equations (10)–(12)) (Table 3). The parameter estimates using 2SLS, which is consistent under the null hypothesis (H_0) as well as the alternative hypothesis (H_a), is tested against parameters obtained from 3SLS, which is efficient under the H_0 but inconsistent under the H_a. The estimated value of χ^2 with 21 degrees of freedom is 27.45 (see Table 3). The Prob. $\chi^2 > \chi^2$ statistic is 0.195 [34].

The next test was performed to check whether raising livestock varies by household categories. The results revealed that the null hypotheses of no influence of household category on raising livestock was strongly rejected at the 1% level of significance for all three models, thereby confirming the implication that the type of livestock raised by householders is influenced by resources and wealth [19,20]. This is because the owned cultivated land, which is the basis used to classify the household categories, is an important indicator of wealth in rural Bangladesh.

The next test was performed to check whether other socioeconomic features jointly influence the number of livestock raised per household. The results revealed that the null hypotheses of no influence of population density, literacy rate, subsistence pressure and R&D investment was strongly rejected at the 1% level of significance for all three models, implying that these factors jointly influence the number of livestock raised per household. The final hypothesis test was to confirm whether agroecological characteristics have an influence on raising livestock. The results revealed that the null hypotheses

of no influence of agroecology on raising livestock is strongly rejected at the 1% level of significance for all three models, thereby confirming that the type of livestock raised by householders varies by agroecological conditions [19,20].

Table 3. Hypothesis tests.

Hypothesis	Joint Determination of Factors Influencing Raising Livestock Using 3SLS Regression Model		
	Cattle Model	Goat/Sheep Model	Poultry Model
Choice of estimation technique			
Hausman test for the choice of estimation technique (3SLS vs. 2SLS) χ^2 (21 df)	27.45		
p-value	0.20		
Decision	Accept 3SLS		
Influence of household type on raising livestock			
Impact of the proportion of four types of households are jointly zero in each structural equation ($F_{4,2990}$)	72.40 *	53.86 *	94.94 *
Influence of socioeconomic factors on raising livestock			
Impact of the population density, literacy rate, subsistence pressure and R&D investment are jointly zero in each structural equation ($F_{4,2990}$)	14.84 *	9.27 *	10.74 *
Influence of agroecology on raising livestock			
Impact of agroecology on raising livestock is jointly zero in each structural equation ($F_{11,2990}$)	24.58 *	36.05 *	29.22 *

Note: * significant at 1% level ($p < 0.01$).

Sixty-seven percent of the coefficients on the variables are significantly different from zero at the 10% level of significance at least, which implies a good fit (Table 4). The value of Adjusted R^2 also reveals that these indicators jointly explain 76% of the total variation in the cattle model, 65% in the goat/sheep model, and 63% in the poultry model, hence reinforcing confidence in our results. The number of all types of livestock raised is significantly higher for the small and medium farms and wage-labour households, although the magnitude of influence is highest for the small farms (Table 3). Since double-log specification was used, the value of the coefficient can be read directly as elasticities. The elasticity values of small farms on livestock raised per household are estimated at 0.39, 0.51 and 0.38 for cattle, goat/sheep and poultry models, respectively. The implication is that a 1% increase in the proportion of small farms will increase the number of cattle raised per household by 0.39%, goat/sheep by 0.51% and poultry by 0.38%, respectively. It is interesting to see that the number of cattle raised is significantly higher for the non-farm households but significantly lower for raising poultry. The implication is that the non-farm households residing in the rural areas, who are not involved in farming as such, are also raising cattle so that they can derive income from livestock and livestock products (i.e., milk and calves) as well as providing draft power services for farming operations through the rental market as conventionally done by farming households in rural areas.

The amount of GCA per household significantly influences the number of cattle per household, with an elasticity value of 0.30. The implication is that a 1% increase in GCA will increase the number of cattle per household by 0.30%, which is expected, since draft power is still one of the major sources of farm power in Bangladesh. There is no influence of irrigation area, owned land size or homestead area on raising livestock. We did not use all four measures of land size, i.e., GCA, irrigated area, owned land and homestead area, together in each equation because of two considerations. First, the choice of variables is based on its relevance. For example, cattle are used for draft power, so GCA and irrigated area appeared in the cattle model. Raising goat does not have any explicit link with GCA or irrigation and hence only owned land is used in this model. It is well known that poultry are largely raised in the homestead and the homestead land area, hence this appeared only in the poultry model. The second consideration is to break potential multicollinearity between these four measures of land by including

variables selectively in each equation. Kumar and Singh [13], using survey data from India, noted that farm size significantly positively influence decisions to keep cattle and buffalo and negatively to keep goat and sheep and poultry, respectively. They also noted that household size significantly positively influence decisions to keep all types of livestock.

Table 4. Impact of agroecological, land-elevation and socioeconomic factors on raising livestock per household in Bangladesh.

Variables	Joint Determination of Factors Influencing Raising Livestock Using 3SLS Regression Model		
	Cattle Model	Goat/Sheep Model	Poultry Model
Intercept	0.570 ***	2.227 ***	2.865 ***
Household categories			
Proportion of non-farm households	0.086 **	0.062	−0.137 ***
Proportion of medium farms	0.325 ***	0.221 ***	0.226 ***
Proportion of small farms	0.396 ***	0.518 ***	0.381 ***
Proportion of labour households	0.058 ***	0.277 ***	0.090 ***
Socioeconomic factors			
Gross cropped area per household	0.302 ***		
Irrigated area per household	−0.001		
Owned land area per household		−0.112	
Homestead area per household			0.048
Subsistence pressure (household size)	−0.032	−0.061	0.037
Rural population density per sq km	−0.019	−0.227 ***	−0.046 *
Literacy rate	0.156 ***	0.014	0.021
R&D investment in livestock sector	0.019 ***	0.011	−0.034 ***
Agroecology			
Old Himalayan Piedmont Plain and Tista Floodplain	0.170 ***	0.376 ***	0.103 **
Karatoa Floodplain and Atrai Basin	−0.026	0.314 ***	0.270 ***
Brahmaputra–Jamuna Floodplain	−0.013	−0.245 ***	−0.011
High Ganges River Floodplain	−0.036	0.401 ***	0.070 *
Low Ganges River Floodplain	−0.176 ***	0.002	−0.071
Ganges Tidal Floodplain	−0.039	−0.059	0.291 *
Sylhet Basin and Surma–Kushiyara Floodplain	0.201 ***	−0.586 ***	0.057
Middle Meghna River Floodplain	0.067 *	−0.030	0.390 ***
Lower Meghna River and Estuarine Floodplain	−0.179 ***	−0.391 ***	0.591 ***
Chittagong Coastal Plain and St. Martin's Coral Island	0.209 ***	−0.319 ***	0.425 ***
Eastern Hills	−0.013	−0.061	0.313 ***
Land elevation			
High land	0.005 **	0.060 ***	−0.013 ***
Medium High Land [a]	−0.003	0.062 ***	0.024 ***
Medium Low Land [a]	−0.011 ***	−0.017 **	−0.009 **
Low Land and Very Low Land [a]	−0.007 ***	−0.039 ***	−0.014 ***
Model diagnostics			
Adjusted R^2	0.755	0.650	0.632
F-value	141.93 ***	90.09 ***	83.84 ***
Degrees of freedom of the system of equation	2993		
Number of observations in each equation	1021	1021	1021

Note: [a] These coefficients are from individual models fitted using only one land-type variable each time in order to avoid high multicollinearity among these variables; *** significant at 1% level ($p < 0.01$); ** significant at 5% level ($p < 0.05$); * significant at 10% level ($p < 0.10$).

Among socioeconomic features, the literacy rate significantly influences raising cattle per household with an elasticity value of 0.16. Kumar and Singh [13], however, noted a significantly negative influence of literacy rate of household head on raising buffalo and goat/sheep in India. Population density significantly reduces the number of goat/sheep and poultry raised per household, which econometrically explains the observed decline in these livestock types between the censuses in Table 2. R&D investment positively influences the number of cattle raised per household but negatively

influences number of poultry raised per household. A 1% increase in R&D expenditure will increase the number of livestock raised by 0.02%.

The influence of agroecology on the number and type of livestock raised per household is significant, and varies across AEZs (Table 4). Adams and Ohene-Yankyera [32], using farm-level survey data, also noted that agroecological characteristics significantly influence a farm household's choice of raising livestock in northern Ghana. Since we have already controlled for a range of socioeconomic features by including them explicitly in the models, the observed influences of agroecology variables are their net effects on the number of livestock raised per household, which is not commonly reported in the literature. It should be noted that since these are dummy variables, the magnitude of influence is discrete in nature and should be interpreted in relation to the 12th AEZ subsumed in the intercept term, which is the Greater Dhaka AEZ. The number of all types of livestock is significantly higher in Old Himalayan and Tista Floodplain, which econometrically confirms the observation made in Table 1. The number of cattle raised per household is significantly higher in Sylhet Basin, Middle Meghna River Floodplain and Chittagong Coastal Plain as well, but significantly lower in Lower Ganges and Meghna Floodplains. The number of goat/sheep raised per household is significantly higher in Karatoa Floodplain and Higher Ganges River Floodplain but lower in the other four AEZs, which explains a lower number of goat/sheep-raising per household in the country. Poultry-raising is significantly higher in the Eastern Hills and seven other AEZs, implying that raising poultry is feasible in most agroecologies.

Land elevation significantly influences the type of livestock raised. The number of cattle raised per household is significantly higher in high land elevations, but significantly lower in medium-low land and low-lying areas (Table 4). As mentioned at the end of Section 2.3, these land elevation variables are significantly negatively correlated among themselves, and we have modelled four separate regressions by including one land-elevation variable at a time. Table 4 presents the results of the model with high land elevation included in the equation. The influence of the other three categories of land elevation variables is from three independent regression models. It is worth noting that general results of all other models are almost identical to that model reported in Table 4, and hence not presented. This is because raising cattle is not suitable in areas prone to flooding. Kumar and Singh [13], using livestock census information from India, also noted that raising cattle and buffalo is high in hilly, mountainous, coastal and rainfed regions. Similarly, the number of goat/sheep raised per household is significantly higher in high and medium-high land areas but significantly lower in medium-low and low-lying areas. Kumar and Singh [13] also noted that raising goat and sheep are highest in arid regions, and pigs in hilly and mountainous regions, of India. In contrast, raising poultry is significantly higher in medium-high lands but significantly lower in high land elevation as well as medium-low land and low-lying areas. Udo et al. [12] noted that poultry is largely raised on homestead land, implying that landscape conditions may not have any influence. But our results show that land elevation does influence the number of poultry raised per household as well.

4. Conclusions and Policy Implications

The aim of this study has been to examine the influence of agroecological, land-elevation and socioeconomic factors on raising livestock by householders in Bangladesh based on sub-district level information from two Agricultural and Livestock Censuses of 1996 and 2008 by using a simultaneous equations model. Results revealed that the number of livestock raised per household varies significantly across AEZs and declined in most AEZs in 2008 from its 1996 level. Also, an unexpected feature of a rising proportion of non-farm households at the expense of a decline in medium and large farms in all AEZs as well as small farms in some of the AEZs was observed. Gross cropped area also declined in all AEZs, while population density and the literacy rate have increased between the two census periods.

Among the socioeconomic determinants of raising livestock, the number of cattle, goat/sheep and poultry raised per household were found to be significantly higher among the medium and small

farms and wage-labour households. Raising cattle is significantly higher for non-farm households, but raising poultry is significantly lower. Gross cropped area per household, literacy rate and R&D investment significantly influence raising cattle, whereas population density negatively influences raising goat/sheep and poultry. Raising livestock is significantly influenced by agroecological characteristics with differential influences.

Agroecological characteristics have a significant but variable influence on the type of livestock raised per household. Livestock (all types) raised per household is significantly higher in the Old Himalayan and Tista Floodplains, and goat/sheep- and poultry-raising are significantly higher in the Karatoa Floodplain and Atrai Basin, Eastern Hills and High Ganges River Floodplain agroecologies too.

Land elevation also exerts a significant and varied influence on the type of livestock raised per household. Raising any type of livestock is not suitable in low-lying areas. Raising cattle and goat/sheep is significantly higher in areas with high land elevation, whereas poultry-raising is significantly lower. However, raising goat/sheep and poultry is also significantly higher in medium-high land areas.

The following policy implications can be drawn from the results of this study. First, investment in R&D for the livestock sector should be enhanced, which will lead to an increase in raising the number of cattle mainly through the adoption of improved breeds, which are potentially characterized by higher production, productivity and better quality. A focus of investment should also be geared towards developing technologies for goat/sheep and poultry so that the declining trend of poultry population can be reversed and, at the same time, the contribution of goat/sheep towards meat and milk supply for the nation can be increased. The Bangladesh Livestock Research Institute (BLRI) developed 67 technologies and packages from 1998 until 2013 [37]. However, the thrust of research at BLRI seems to have focused on large ruminants, particularly cattle (e.g., improving milk production, fodder and feed, breeding, genetic screening, artificial insemination, pest control, etc.). Although some research was also undertaken on poultry (e.g., avian influenza and diseases, salmonella vaccine, poultry-raising models, marketing value-chain analysis, etc.) and goat/sheep (e.g., goat-raising packages, calf-management and goat vaccines), further research should be geared towards goat and poultry in addition to cattle and buffalo [37]. Second, investment in education targeted at the farming population will improve livestock-raising, particularly cattle. Third, tenurial reform aimed at consolidating farm size and/or gross cropped area per household will support this. The average farm size in Bangladesh is declining rapidly and land fragmentation is increasing [35] with 12.84% of households owning no land according to the 2008 census [26]. Average farm size declined from 0.81 ha in 1996 to 0.49 ha in 2005 [38]. Therefore, tenurial reform aimed at the smooth operation of the land-rental market along with effective implementation of the tenancy act will enable more households to enter farming as well as increase farm-operation size, which in turn will improve cattle-raising per household and contribute to supporting farming and milk and meat production. Fourth, measures should be undertaken to promote different types of livestock suited to specific AEZs, since agroecological features exert a differential influence on the type and number of livestock raised per household. For example, measures to improve poultry-raising can be targeted in a wide range of agroecologies. Fifth, measures should be undertaken to promote different types of livestock suited to specific land-elevation areas. For example, cattle-raising should be targeted at high land areas, whereas goat/sheep and poultry-raising should be targeted at medium-high land areas.

Although realising these policies is challenging, an improvement in livestock resources is important for the economy in order to meet increasing demand for milk, meat and eggs as well as to support farming operations through draft-power services, which is a goal worth pursuing.

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References

1. Pica-Ciamarra, U. *Livestock Policies for Poverty Alleviation: Theory and Practical Evidence of Africa, Asia and Latin America*; Pro-Poor Livestock Policy Initiative Working Paper No 27; FAO: Rome, Italy, 2005.
2. Seré, C.; van der Zijpp, A.J.; Persley, G.; Rege, E. Dynamics of livestock production systems, drivers of change and prospects for animal genetic resources. *Anim. Genet. Res. Inf.* **2008**, *42*, 3–24. [CrossRef]
3. Rosegrant, M.W.; Fernandez, M.; Sinha, A. Looking into the future for agriculture and AKST. In *International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD), Agriculture at a Crossroads*; McIntyre, B.D., Herren, H.R., Wakhungu, J., Watson, R.T., Eds.; Island Press: Washington, DC, USA, 2009; pp. 307–376.
4. Hurst, P.; Termine, P.; Karl, M. *Agricultural Workers and Their Contribution to Sustainable Agriculture and Rural Development*; FAO: Rome, Italy, 2005; Available online: ftp://ftp.fao.org/docrep/fao/008/af164e/af164e00.pdf (accessed on 23 December 2017).
5. Thornton, P.K. Livestock production: Recent trends, future prospects. *Philos. Trans. R. Soc. B* **2010**, *365*, 2853–2867. [CrossRef] [PubMed]
6. Wright, I.A.; Tarawali, S.; Blummel, M.; Gerard, B.; Teufel, N.; Herrero, M. Integrating crops and livestock in subtropical agricultural systems. *J. Sci. Food Agric.* **2012**, *92*, 1010–1015. [CrossRef] [PubMed]
7. Alexandratos, N.; Bruinsma, J. *World Agriculture towards 2030/2050: The 2012 Revision*; ESA Working Paper No. 12–03; FAO: Rome, Italy, 2012.
8. Herrero, M.; Thornton, P.K.; Notenbaert, A.; Msangi, S.; Wood, S.; Kruska, R.; Dixon, J.; Bossio, D.; van de Steeg, J.; Ade Freeman, H.; et al. *Drivers of Change in Crop–Livestock Systems and Their Potential Impacts on Agro-Ecosystems Services and Human Wellbeing to 2030: A Study Commissioned by the CGIAR Systemwide Livestock Programme*; International Livestock Research Institute: Nairobi, Kenya, 2012.
9. Rojas-Downing, M.M.; Nejadhashemi, A.P.; Harrigan, T.; Woznicki, S.A. Climate change and livestock: Impacts, adaptation and mitigation. *Clim. Risk Manag.* **2017**, *16*, 145–163. [CrossRef]
10. Tarawali, S.; Herrero, M.; Descheemaeker, K.; Grings, E.; Blümmel, M. Pathways for sustainable development of mixed crop livestock systems: Taking a livestock and pro-poor approach. *Livest. Sci.* **2011**, *139*, 11–21. [CrossRef]
11. Uddin, M.M.; Hylenbroeck, G.V.; Hagedorn, K.; Sultana, N.; Peters, K.J. Institutional and organisational issues in livestock service delivery in Bangladesh. *Q. J. Int. Agric.* **2010**, *49*, 112–125.
12. Udo, H.M.J.; Aklilu, H.A.; Phong, L.T.; Bosma, R.H.; Budisatria, I.G.S.; Patil, B.R.; Samdup, T.; Bebe, B.O. Impact of intensification of different types of livestock production in smallholder crop-livestock systems. *Livest. Sci.* **2011**, *139*, 22–29. [CrossRef]
13. Kumar, A.; Singh, D.K. Livestock production system in India: An appraisal across agro-ecological regions. *Indian J. Agric. Econ.* **2008**, *63*, 577–597.
14. Dhakal, C.K.; Regmi, P.P.; Dhakal, I.P.; Khanal, B.; Bhatta, U.K. Determinants of livestock holders' adaptive capacity to climate change in Gandaki River Basin, Nepal. Handbook on the Economic, Finance and Management Outlooks. In Proceedings of the ICEFMO, Kuala Lumpur, Malaysia, 5–6 October 2013; pp. 255–263.
15. Rahman, S.; Begum, I.A.; Alam, M.J. Livestock in Bangladesh: Distribution, growth, performance and potential. *Livest. Res. Rural Dev.* **2014**, *26*, 173.
16. Begum, I.A.; Alam, M.J.; Buysse, J.; Frija, A.; Huylenbroeck, G.V. A comparative efficiency analysis of poultry farming systems in Bangladesh: A Data Envelopment Analysis approach. *Appl. Econ.* **2011**, *44*, 3737–3747. [CrossRef]
17. IMF. *Bangladesh Poverty Reduction Strategy Paper*; International Monetary Fund Country Report No. 04/410; IMF: Washington, DC, USA, 2005.
18. LPAP. *Livestock Policy and Action Plan 2005*; Department of Livestock Services, Ministry of Fisheries and Livestock, Government of Bangladesh: Dhaka, Bangladesh, 2005.
19. Bosma, R.H.; Phong, L.T.; Kaymak, U.; van den Berg, J.; Udo, H.M.J.; van Mensvoort, M.E.F.; Tri, L.Q. Assessing and modelling farmers' decision-making on integrating aquaculture in the Mekong Delta. *NJAS* **2006**, *53*, 281–300. [CrossRef]
20. Kristjanson, P.; Krishna, A.; Radeny, M.; Nindo, W. *Pathways Out of Poverty in Western Kenya and the Role of Livestock*; FAO/PPLPI Working Paper No 14; FAO: Rome, Italy, 2004.

21. Rahman, S. The economic determinants of crop diversity on farms in rural Bangladesh. *J. Int. Agric. Trade Dev.* **2008**, *5*, 51–70.

22. Rahman, S. Impacts of climate change, agroecology and socio-economic factors on agricultural land use diversity in Bangladesh (1948–2008). *Land Use Policy* **2016**, *50*, 160–178. [CrossRef]

23. Isik, M. Environmental Regulation and the Spatial Structure of the US Dairy Sector. *Am. J. Agric. Econ.* **2004**, *86*, 949–962. [CrossRef]

24. Benin, S.; Smale, M.; Pender, J.; Gebremedhin, B.; Ehui, S. The economic determinants of cereal crop diversity on farms in the Ethiopian Highlands. *Agric. Econ.* **2004**, *31*, 197–208. [CrossRef]

25. Bangladesh Bureau of Statistics. *Census of Agriculture and Livestock in Bangladesh, 1996*; Bangladesh Bureau of Statistics: Dhaka, Bangladesh, 1997.

26. Bangladesh Bureau of Statistics. *Census of Agriculture in Bangladesh, 2008*; Bangladesh Bureau of Statistics: Dhaka, Bangladesh, 2010.

27. Bangladesh Bureau of Statistics. *Community Report of Population and Housing Census, 2011 (Various Issues)*; Bangladesh Bureau of Statistics: Dhaka, Bangladesh, 2012.

28. Dey, M.; Evenson, R.E. *The Economic Impact of Rice Research in Bangladesh*; BRRI/IRRI/BARC: Dhaka, Bangladesh, 1991.

29. Bangladesh Agricultural Research Council BARC. Climate and LRI Database. Bangladesh Agricultural Research Council. Available online: http://www.barcapps.gov.bd/dbs/index.php?t=land_du (accessed on 27 December 2017).

30. UNDP-FAO. *Land Resources Appraisal of Bangladesh for Agricultural Development*; Report to Agro-Ecological Regions of Bangladesh; BGD/81/035 Technical Report 2; UNDP-FAO: Rome, Italy, 1988; p. 570.

31. Quddus, M.A. Crop production growth in different agro-ecological zones of Bangladesh. *J. Bangladesh Agric. Univ.* **2009**, *7*, 351–360. [CrossRef]

32. Adams, F.; Ohene-Yankyera, K. Determinants of factors that influence small ruminant livestock production decisions in Northern Ghana: Application of Discrete Regression model. *J. Biol. Agric. Healthc.* **2014**, *27*, 310–321.

33. Rahman, S. Agroecological, climatic, land elevation and socio-economic determinants of pesticide use at the farm level in Bangladesh. *Agric. Ecosyst. Env.* **2015**, *212*, 187–197. [CrossRef]

34. StataCorp. *STATA Version 10*; Stata Press Publications: College Station, TX, USA, 2008.

35. Rahman, S.; Rahman, M. Impact of land fragmentation and resource ownership on productivity and efficiency: The case of rice producers in Bangladesh. *Land Use Policy* **2008**, *26*, 95–103. [CrossRef]

36. Niroula, G.S.; Thapa, G.B. Impacts and causes of land fragmentation, and lessons learned from land consolidation in South Asia. *Land Use Policy* **2005**, *22*, 358–372. [CrossRef]

37. Bangladesh Livestock Research InstituteLRI. *Annual Research Report, 2013–14*; Bangladesh Livestock Research Institute: Savar, Bangladesh, 2015.

38. Nasrin, M.; Uddin, M.T. Land tenure system and agricultural productivity in a selected area of Bangladesh. *Prog. Agric.* **2011**, *22*, 181–192. [CrossRef]