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Original Article

Composite Green Rating System for Enhancing Rural Area with Infrastructure, Environmental, and Sustainable Development Predicting Risk Analysis

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Abstract - *Rural development requires interaction among many social, economic, and environmental factors along a growth trajectory significantly different from that which occurs in cities. In fact, rural territories very often present some critical limitations, such as scarce services, scattered distribution of resources, and greater vulnerability to environmental changes. With this in mind, sustainable development strategies must balance necessary infrastructure support with responsible resource management. The present study aims to proffer a CGRS that can be employed for the assessment and comparison of the sustainability of rural settlements using a set of structured and clearly definable environmental, infrastructural, and socio-economic indicators. The framework integrates sustainability evaluation with elements of risk assessment, with particular attention to the role of renewable energy use in village-level development. Field surveys were conducted in three villages of Sangli district, Maharashtra, representing diverse ecological and developmental conditions: Padmale (riverine), Bilashi (hilly), and Dorli (arid). The results showed that Bilashi had the highest score for CGRS, 2.69, closely followed by Padmale, 2.68, indicating only moderate variations in the sustainability performance of these villages. Dorli scored comparatively lower, 2.64, mainly because of its poor water-quality management and limited adoption of renewable sources of energy. The research derives policy recommendations for regional development planning from decentralized energy generation, green infrastructure, and sustainable community projects to close this knowledge gap and enhance rural environmental resilience. The CGRS framework introduces a scalable, data-driven policy planning framework for policy planners to quantify rural sustainability performance, as well as guide interventions for development.*

Keywords - *Composite green rating system, Eco-integrity, Environmental analysis, Infrastructure development, Risk analysis, Rural development, Sustainable development.*

1. Introduction

The concept of sustainable rural development has gained momentum the world over in recent times, as countries are trying to achieve the trifecta of environmental protection, social justice, and economic development simultaneously [1]. Rural regions differ from their urban counterparts in that they have their own set of problems emanating from scattered populations, poor infrastructure, and dependence on nature. Although rating systems such as LEED, IGBC, and GRIHA [2] have been in extensive use when evaluating urban development, their direct use in evaluating rural scenarios has been comparatively limited. Traditional urban rating systems have their focus on compact settlements, high energy efficiency, advanced waste management, and transport networks. While rural development calls for an integrated approach related to environmental, infrastructural, and sustainable development variables coupled with inherent risks due to climatic and ecological factors. Since they are aligned with the United Nations (UN) Sustainable Development Goals (SDGs), the requirement for sustainable development is also emphasized in the rural areas [3]. Factors such as access to clean water, use of renewable energy, efficiency in waste management, soil preservation, and public health directly translate to SDGs touching on clean water and sanitation (SDG 6), clean and affordable energy (SDG 7), climate action (SDG 13), and sustainable communities (SDG 11) [4]. Therefore, inclusion of such factors in a systematic assessment framework helps policy developers to recognize gaps, rank interventions, and track progress towards the attainment of global sustainability goals.

However, previous research on green rating systems has investigated methods from composite indexes to weighted scoring of environmental, infrastructural, and social factors [5]. Methods frequently applied are surveys, field measurements, remote sensing, and scoring models that convert various indicators to a uniform scale. In spite of such developments, there remain numerous limitations. A large majority of rating schemes are urban-oriented, focusing on energy efficiency and high-technology solutions, which could prove unaffordable or irrelevant in rural settings [7]. Scarcity of data, heterogeneity of rural settlements, and variability of ecological conditions-e.g., flood-prone areas along rivers, hilly areas, or drought lands-are major challenges to applying the conventional rating norms. In addition, existing problems in rural development persist, including infrastructural shortages, budget constraints, and vulnerability to natural disasters [8], but are not yet adequately described in most models.

Hence, there must be a rural-friendly composite green rating system that specifically encompasses environmental, infrastructural, and sustainable development, along with risk analysis to meet climatic and ecological exposures. As compared to the context of urban systems, the rural-based context emphasizes resource efficiency, resilience, and flexibility in order to address the particular socio-environmental dynamics of rural landscapes. This improves decision-making as well as a systemic ground for fostering sustainable, equitable, and resilient rural development.

The most pressing problem concerning the rating systems for rural sustainability involves the fact that these rating systems are based on urban-oriented frameworks, failing to capture the essential village-level social and ecological, and livelihood realities. Most of the models proposed for green rating have focused on urban infrastructure; hence, this has left a clear research gap in developing a rural-specific composite assessment system that combines environment, economy, livelihood, and basic infrastructure. Moreover, there is also a lack of quantitative scoring frameworks that could be applied at the village level to project the actual performance across multiple sectors. Thus, the proposed CGRS is filling the research gap by providing a dedicated rural model for evaluating villages in accordance with the UN Sustainable Development Goals, such as clean water, energy access, climate resilience, and sustainable communities. Its novelty is that it was adapted for rural landscapes, whereas the other models, like LEED-India, IGBC, GRIHA, and others, have focused on cities. Finally, CGRS also introduces a multi-criteria composite scoring methodology adapted for rural socio-economic and ecological environments, which comprises quantifiable indicators for livelihood, natural resource management, and infrastructure quality, apart from a ranking system linked to the evaluation that will eventually support evidence-based rural planning and policy interventions.

The CGRS is thus a contextual, substantive assessment model based on geographical constraints, socio-economic assortment, and resource dependence, relevant to rural settings. It goes beyond the narrow realm of infrastructure readiness or technological adoption. In putting together environmental quality, use of renewable energy, risk exposure, and community participation, it constructs a realistic profile of sustainability. This also resonates with the ground realities of rural India very closely, where livelihood needs become an important guiding factor in development priorities within the paradigm of climatic uncertainty. The CGRS reduces complex and multi-dimensional features of sustainability into quantifiable scores; it takes up yet another strategic role in planning targeted improvements and monitoring the progress of village development against the UN SDGs.

The proposed technique of this study includes three sample villages to span different conditions of rural areas, such as geographical, infrastructure, and environmental variations. Therefore, this allows for the comparison of performance for sustainability under varying conditions of socio-ecological settings in terms of sustainability processes, environmental quality, infrastructure adequacy, and hazard evaluation. Additionally, it is also a comprehensive assessment framework. The paper proposes including parameters within a CGRS for rural settings that fill in some of the gaps in rating systems. Valuable input from the research was used in policy-relevant recommendations supplied to policymakers and planners for facilitating targeted interventions toward rural resilience and sustainability.

The research objectives include:

- To create a Composite Green Rating System (CGRS) appropriate for rural sustainability evaluation.
- To evaluate the environmental, infrastructural, and sustainable development performance of the selected villages.
- To determine and quantify ecological and climatic condition-related risks in rural areas.
- To compare rural sustainability indicators with existing urban rating system parameters.
- To provide actionable suggestions towards enhancing resilience and promoting sustainable rural development

1.1. Research Questions

The research is in line with the Sustainable Development Goals of the UN. It directly corresponds to SDG 11 on sustainable cities and communities, SDG 6 on clean water and sanitation, SDG 13 on climate action, as well as SDG 7 on clean and affordable energy. Framing the research questions within the context of the SDGs ensures that the relevance is global in scope, while the challenge addressed is locally grounded in rural India.

- How do infrastructural, environmental, and sustainability parameters vary across villages with the strongest influence on the Green Rating Score?
- How do the rural awareness and willingness to adopt renewable energy and sustainable practices align with SDG 6, SDG 7, SDG 11, and SDG 13?
- How do village-specific risks affect sustainability performance within rural settings?
- Compared to the existing urban sustainability benchmarks, how is the proposed CGRS framework efficient?
- Which improvements can help the sustainable development in selected rural communities?

2. Literature Review

Rural sustainability has been an increasing concern identified as an urgent need for frameworks of assessment that capture the environmental quality, resource management, and community well-being. Traditional metrics of rural development tend to emphasize infrastructure and economic growth, but leave ecological balance, renewable energy adoption, and participatory governance trailing behind. With recent far-reaching policy transitions toward greener economies, there is a need for measurable indicators. These indicators provide information for planning, monitoring progress, and benchmarking outcomes at the community level. CGRS is the composite guide to facilitate multi-dimensional assessment in a manner consonant with emerging priorities for sustainability. Such frameworks form the basis necessary for evidence-informed decision-making, ensuring that performance gaps are identified and accountability is increased through government and local stakeholders.

In recent development, village-specific evaluation techniques are more vital since the villages possess distinctive ecological, economic, and infrastructural features. Thus, a SWOT assessment, represented by Ali et al. [9], included Eastern India's hill, riverine, and arid zones through resource inventories and community surveys. Their mixed-methods analysis determined environmental constraints and socio-cultural strengths that are not typically measured with common quantitative indicators. Each of these studies emphasizes the value of participatory diagnostic methods as an instrument of rural sustainability assessment that has a specific direct application to this research's Sangli village strategy. Smart Villages have been defined by Gerli et al. [10] as those which effectively integrate local knowledge, participative management, and information and communication technologies in order to improve services and resilience.

Eco-village experiments have revealed measurable gains in sustainability through local-scale infrastructural interventions. Kumavat et al. [11] experimented with a semi-arid village in Maharashtra by implementing decentralized technologies such as roof solar panels, rainwater harvesting, and compost toilets, coupled with people's participation. The usage of energy decreased, and nearly one-third less water was consumed in 18 months. Use of Information and Communication Technology (ICT) in rural administration has also enhanced the assessment of sustainability. Sabir et al. [12] have found that IoT-based irrigation and mini solar microgrids for rural Indian villages raised water-use efficiency by 30% and reduced energy costs by 25%, with effectiveness dependent on efficient local institutions. Kochhar et al. [13] examined city green rating systems such as LEED and GRIHA critically and arrived at the conclusion that the models are incapable of capturing basic rural parameters such as agricultural water management, decentralised energy supply, sanitation, and social inclusion. They advocated for rural-exclusive models that can trace the environment and socio-infrastructural measures in village decision-making.

Participatory action research emerged as the driving force of rural sustainable development. Ricket et al. [14] advocated for a "social enterprise ecosystem" orientation, demonstrating how combining local institutions, entrepreneurial networks, and environmental schemes can harmonize livelihoods with sustainability objectives. Climate and economic shock adaptation is essential for rural sustainability. Der Tambile et al. [15] developed models that combined resource management, digital networks, and resilience indicators to respond to environmental and market stresses. The research [16] contrasted riverine villages with flood susceptibility with hilly forest-dependent villages and demonstrated that context-specific early warning and ecosystem-based risk reduction are needed. These findings guided the integration of resilience in the comparative and SWOT analysis of this research in three Sangli villages. Cuenca-Enrique et al. [17], in their systematic review of international rural electrification projects, emphasized that social capital, participatory planning, and local governance arrangements are more likely to overcome technology type or funding status as project success predictors in the long run. Renukappa et al. [18] brought forward the issue that the resilience of ICT-based interventions relies on good governance, good-quality data, and mutual institutional incentives. These results emphasize the need for considering operational sustainability as well as governance while assessing rural performance. Katoch et al. [19] also emphasized the need for local ownership in the case of community solar microgrids, with a demonstration of 70% job creation and 40% carbon emissions savings with strong institutional support.

Concurrently, Mohapatra et al. [20] examined rural retrofitting of houses with passive heating controls, solar water heating, and greywater reuse. Performance evaluation indicated that 80% of the retrofitted homes achieved net-zero energy, and indoor comfort increased by 20–35%. The research work is technical precedents and performance objectives for environmental and infrastructure needs in rural green ratings. Nasution et al. [21] consolidated more than 100 South Asian studies, and they determined that sustainable agriculture, access to the internet, and active community involvement are the three pillars for independent, adaptive villages. As a collective, these studies affirm that governance and participation must be given conscious consideration in any green rating scheme for rural areas.

Precision agriculture, with the support of IoT and remote sensing, has also improved efficiency. Shahab et al. [22] reported mean yield increases of 20–30% with 25–40% reductions in water and fertilizer use in 100 rural case studies. Dhal & Kar [23] explained AI-based prediction models like SARIMA and deep-learning hybrids for sub-regional yield prediction and supply-chain optimization, referring to the imperatives of enhanced data infrastructure in smallholder settings. These studies justify the inclusion of technological effectiveness and prediction in SWOT-based rural studies.

Moreover, recent studies demonstrate increasing momentum towards rural sustainability; however, the existing approaches remain fragmented and often context-limited. Devi et al. [24] highlighted the need for policy alignment across the energy, agriculture, construction, and transport sectors in order to transition India towards a green economy, and pointed out that systemic rather than isolated interventions will be required. Thomas et al. [25] conducted a bottom-up review of renewable energy deployment in rural India and made the case for energy-water-food nexus thinking, arguing further that renewable adoption needs to be assessed against livelihood outcomes rather than merely technological deployment. Krishnendu et al. [26] demonstrated the value of participatory rural appraisal and human-centered design in showing that community involvement significantly enhanced problem identification and solution acceptance. Outside the Indian context, Zhang and Tian [27] introduced a grey-AHP-based evaluation model for "green villages" in China and showed that structured indicator systems can unveil regional disparities and help guide targeted development. Also, Abed et al. [28] advanced mixed-methods evaluation frameworks by demonstrating that quantitative scoring combined with stakeholder narratives enhanced the relevance and policy applicability of assessments.

Recent Indian empirical research demonstrates place-based, thematic interventions to tackle environmental, energy, water, sanitation, and agricultural sustainability. Village-level examples include afforestation, control of pollution, harvesting of rainwater, sanitation infrastructure, renewable energy, and precision agriculture in villages such as Betul, Hiware Bazar, and Ralegaon Siddhi, which demonstrate the importance of context-specific interventions. However, there are some limitations: eco-village and retrofit studies rarely compare different ecological contexts, Smart Village schemes typically do not have long-term operational assessments, resilience strategies tend to be abstract, and there are few comparative village-level studies that include environmental, infrastructural, technological, and governance considerations. With the integration of these results, this present study contributes to rural sustainability studies through extensive village typology reporting, participatory SWOT analysis, cross-context environmental and infrastructural parameter benchmarking, and embedding risk assessment, thereby filling crucial gaps in current green rating systems.

2.1. Research Gap

Despite the previous studies on rural sustainability, eco-village models, Smart Village initiatives, and community interventions, some research gaps still exist with an adequate holistic evaluation of rural development with regard to green rating systems.

- There are no comparative studies available in the research on villages with different ecological, climatic, and socio-economic conditions.
- Existing models are urban-based and do not incorporate rural-specific parameters like decentralized energy, water management, and community participation.
- Long-term operational viability and intervention durability have not been investigated sufficiently.
- Integrated assessment involving environmental, infrastructural, technological, and risk factors is rarely practiced at the village level.
- Few studies provide quantitative, data-driven scoring systems for benchmarking and prioritization in rural areas.

The study filled the gaps by selecting for comparison three ecologically disparate villages, developing a Composite Green Rating System (CGRS) unique to rural sustainability that includes environmental, infrastructure, and risk factors as well as participatory governance factors, and employing quantitative 0–5 scoring for ease of standardized benchmarking and evidence-based recommendations.

3. Proposed Methodology

The research methodology employed in the study follows a scientific methodology for evaluating rural sustainability based on a Composite Green Rating System (CGRS). Data is collected through household surveys, field observation, and community involvement to obtain information on environmental, infrastructural, and socio-economic parameters. They are quantified and scaled to 0–5 in order to compare different villages. Scores on the Environmental, Infrastructure, Sustainability, and Risk dimensions are calculated for each respondent and then aggregated to get village-level performance indexes. Participatory SWOT analysis is also applied in the methodology for the selection of local strengths, weaknesses, opportunities, and threats in order to make it contextually relevant. The given framework for the assessment of rural sustainability is flexible and inclusive, based on the data used in the assessment.

3.1. Selection of Villages

Three villages from Maharashtra's district of Sangli were purposively selected for this research to draw out a general understanding of rural sustainability within varied environmental and geographical contexts. Each village represents a separate ecological context, such as drought, hilly, and riverside.

The selection criteria for the villages were based on accommodating all forms of diversity in rural conditions, as well as environmental stressors. It considers selection based on topographic variation: drought-prone, riverside, and hilly areas. It also takes into consideration factors based on variation in population size and associated climate-related hazards of water scarcity, flooding, or limitations imposed by the terrain. In addition, the available basic infrastructure, dependency on natural resources, and socio-economic diversity allow for the derivation of an overall picture of sustainability. This would ensure that the selected sites capture the full spectrum of rural development challenges relevant to CGRS evaluation.

Dorli village, Tasgaon Taluka, which is located at a latitude of 17.11222 and a longitude of 74.6856 with a population of 1,961, represents low water availability areas with arid climatic conditions and huge scope for solar power utilization. Bilashi in Shirala Taluka, at Latitude 17.00007, Longitude 74.01154, and population 3,674, is hilly with undulations and slopes, scattered habitations, and poor infrastructure. However, the wind conditions are pretty good. Padmale village in Miraj Taluka is located at a latitude of 16.8943 and a longitude of 74.55395, with a total population of 2,692. The village has a riverbank area with fertile soil and good water availability, but it is flooded during the rainy monsoon period. Selection enables a comparative assessment of different natural and geographical conditions on infrastructure development, sustainable development, and environmental resilience in rural Maharashtra.

3.2. Sampling Technique

The study utilized stratified sampling that confirms appropriate representation for each household from the geographical, social, and economic divisions in every village. This also encompasses respondent groups like laborers, farmers, and small business owners regarding different patterns of energy use and access to basic infrastructure. This helped the study in capturing the inner diversity inside the community and reduced any chance of possible bias in the process of sampling. Around 70% of households are sampled in each sample village, which gives reliable statistics with appropriate representation. The distribution is as follows:

- Dorli (Drought-prone) – 300 households out of 433 total households
- Bilashi (Hilly terrain) – 600 households from about 856 total households
- Padmale (Riverside) – 380 households from 540 total households

This sample size was sufficient to provide a good dataset for examining sustainability indicators, access to infrastructure, and environmental performance measures across the three types of rural areas. The results from the data collected were later used to compute the CGRS scores to aid in the comparative evaluation of the environmental quality, adequacy of infrastructure, and sustainability measures of the regions concerned.

3.3. Survey Methodology

The stratified random technique in every selected village ensures adequate representation from various socio-economic as well as demographic sections. As many as 300 houses in Dorli, 600 houses in Bilashi, and 380 houses in Padmale were covered in this survey, accounting for nearly 70 percent of all houses in each of these concerned villages.

The study also included ethical considerations, with written informed consent obtained from the participants. The participants were given clear explanations of the intent of the study, and any chance of withdrawing from the study at any stage was afforded to them. Stakeholders' consultations involve the authorities in villages, community leaders, and local institutions for transparency, cultural sensitivity, and responsible use of information collected.

Stratification variables used included groups of caste or community, occupation, income, and geographical area to ensure controlled representation of the various social and locational segments. Data were collected through a guided, structured questionnaire in both English and Marathi to achieve clarity and uniformity in the responses of the participants. Enumerators had prior training in ethical principles and methods of unbiased data collection to reduce bias. The tool contained closed questions on quantitative measures and some semi-structured items to elicit views of the community and qualitative information. Additionally, the infrastructure status, waste and water management, sustainability practices, local environmental governance, and risk factors were included in the questionnaire at the village level.

Additionally, water quality results for routine parameters were collected from respective village administrations: pH (6.5–8.5), E. coli (0 MPN/100 ml), color (clear), and odor (odorless). In order to assess the safety and reliability of the local water supply, it was tested for borewells, springs, rivers, wells, taps, and tanks. It confirms the subjective perception of the residents regarding the quality of water in the respective villages. A pilot survey was conducted among 20 households from the entire study area to refine the questionnaire, reducing ambiguity and ensuring its dependability. The instrument showed good internal consistency, with Cronbach's alpha scores higher than 0.7 for major domains. Furthermore, triangulation of census data and Gram Panchayat records enhanced the overall validity and reliability of the findings.

3.4. Data Processing

It includes the calculation of the percentage response by survey parameter by village. A tabulation of all data from the surveys was done first in a systematic manner by village typology, such as hilly, riverside, and drought-prone. Every set of responses was coded under predefined indicators in four broad categories. The environmental parameters included waste collection, water treatment practices, waste segregation, quality and source of water, composting, sanitation, final disposal of solid waste, rainwater harvesting, green cover, air quality, and intensity of noise. Infrastructural parameters included such aspects as the quality of the road infrastructure, toilets in the residential unit, and the availability of health centers. The Sustainability Parameters indexed renewable energy technology adoption dimensions related to organic farming, use of biogas, solar power, and an inclination towards the adoption of renewable energy technology. Village-specific risk parameters indexed the degree of awareness of risk and general satisfaction with the state of the environment and infrastructure. It provided a robust framework for inter-village performance comparison through the calculation of the percentage response at indicator levels for future scores of CGRS and inter-village assessments.

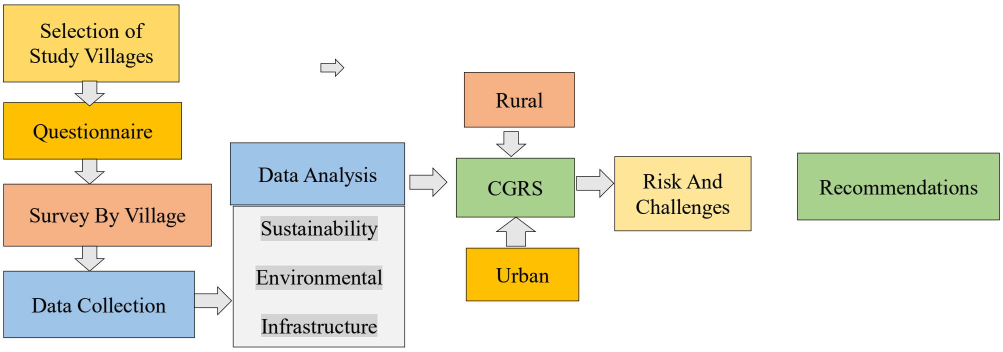

Fig. 1 Proposed methodology for identifying CGRS and risk analysis

3.5. Data Analysis

In data analysis, a transparent and reproducible framework for scoring enhances methodological rigor. All responses from surveys were standardized on a uniform 0-5 scale to make them comparable across different qualitative and quantitative indicators. Binary responses were mapped directly to either 0 or 5, while ordinal variables follow a stipulated, clearly defined scoring rubric. For instance, the rating for environmental quality or infrastructure condition could be rated as poor, moderate, or good. Composite scores by thematic domains, which include environmental performance, adequacy of infrastructure, sustainability of practices, and resilience against risks, are generated by averaging parameter-level scores. Further, descriptive analysis, normality checks, and internal reliability testing support the consistency and interpretive strength of the results. Finally, an overall Composite Green Rating Score (CGRS) categorizes village performance into sustainability tiers that enhance clarity for policy application and comparative evaluation.

3.6. Development of Composite Green Rating System (CGRS)

The study developed a pilot CGRS to measure aggregate sustainability performance and compare it across identified villages. It converts various measures of sustainability along with environmental and infrastructural parameters into an equalized 0-5 scoring system, thereby allowing the normalization of the parameters and villages for comparison. All responses to surveys have been coded in numbers according to predefined rules of scoring. For binary parameters, 5 was assigned for positive responses (“Yes”) and 0 for negative responses (“No”). For categoric parameters such as Air Quality, a graduated scale was employed as Poor (1), Moderate (3), and Good (5) to indicate variation in quality or performance levels. Following data conversion, the 0–5 score was given to every respondent for every one of the significant parameters, giving rise to a uniform dataset accessible to comparison and computation of category-wise means. Parameter scores of an individual were then incorporated into four main factor categories, such as environmental score, infrastructure score, sustainability score, and risk score, by taking the average values of their respective parameters. The total green rating score was then obtained by taking the average of these category scores.

For each village, this composite score captures an indication of the sustainability status. For ease of interpretation, grouped aggregate scores were further categorized into four green rating bands as Platinum (4.25–5.00), Gold (3.50–4.24), Silver (2.50–3.49), and Certified (<2.50). It distinguishes villages on the effectiveness of their environmental management, the sufficiency of infrastructure, and the performance in renewable adoption, thereby allowing focused interventions and policy priorities to be undertaken.

Green Rating and Total Score

- Platinum 4.25 – 5.00
- Gold 3.50 – 4.24
- Silver 2.50 – 3.49
- Certified < 2.50

3.7. Mathematical Model

To compare village-level sustainability on a standard basis, survey responses for various parameters are initially transformed into measurable scores. This is done through the determination of the percentage of affirmative responses for a parameter, followed by scaling them to 0–5. These scaled scores are used as the input for calculating category-wise and Composite Green Rating System (CGRS) values.

The initial step is the calculation of the percentage of positive answers to each parameter in a village, which is given as:

$$\Pi_{i,v} = \frac{1}{R_v} \sum_{r=1}^{R_v} P_i(r,v) \times 100 \qquad (1)$$

Here, $\Pi_{i,v}$ is the proportion of respondents in village v who answered positively for parameter i. R_v is the number of respondents in the village, and $P_i(r, v)$ is the raw survey response of the r-th respondent for the parameter. The indicator function $1(\cdot)$ returns a value of 1 if the condition holds (i.e., a positive answer) and 0 otherwise. This calculation normalizes individual responses to a similar prevalence measure in all the villages.

The second step is to standardize these percentages onto a 0–5 scale so that all parameters can be rolled up consistently. This is achieved by:

$$P_{i,j}(r) = f_i(\Pi_{i,v}) = 5 \cdot \frac{\Pi_{i,v}}{100} \quad (2)$$

In this, $P_{i,j}(r)$ is the normalized score on parameter i under category j for respondent r, while $f_i(\cdot)$ is the normalization function. By linearly scaling the percentage $\Pi_{i,v}$, the score is transformed into a 0–5 scale, where 5 captures the best performance or sustainability fit. This normalized score is then used in calculating category-wise and aggregate CGRS values.

3.7.1. Composite Green Rating System (CGRS)

For the quantitative assessment of the sustainability performance of every village, a Composite Green Rating System (CGRS) was developed with a framed mathematical model. The model aggregates various indicators from four categories, like Environmental, Infrastructure, Sustainability, and Risk, to produce a single consolidated performance index on a normalized scale ranging from 0 to 5. Let P_{ij} be the score of the i-th parameter in the j-th category for a respondent r. Each parameter has been assigned a score ranging from 0 to 5, with higher scores indicating improved performance or sustainability alignment. The respondent's category-wise score is calculated as the arithmetic mean of the parameter scores in the particular category, as given below:

$$S_j^{(r)} = \frac{1}{n_j} \sum_{i=1}^{n_j} P_{ij}^{(r)} \quad (3)$$

Where $S_j^{(r)}$ is respondent r's average score for category j (Environmental, Infrastructure, Sustainability, or Risk), n_j is the number of parameters in category j, and $P_{ij}^{(r)}$ is the normalized score (0–5) for the i-th parameter in category j.

Each respondent's overall composite score (CGRS) is then determined as the average of category scores:

$$CGRS^{(r)} = \frac{1}{m} \sum_{j=1}^{m} S_j^{(r)} \quad (4)$$

Where $CGRS^{(r)}$ is the Composite Green Rating Score for respondent r and m is the Total number of factor categories (here $m=4$ for *Environmental, Infrastructure, Sustainability, Risk*)

The village-level composite score ($CGRS_v$) is calculated by taking the average of the individual respondent scores in the village:

$$CGRS_v = \frac{1}{R_v} \sum_{r=1}^{R_v} CGRS^{(r)} \quad (5)$$

Where $CGRS_v$ is the final Composite Green Rating Score for village v, and R_v is the Total number of respondents surveyed in village v.

The resultant $CGRS_v$ score exists on a 0–5 scale, which is subsequently translated into sustainability performance levels as presented in the study. This allows for comparability, objectivity, and transparency in evaluating sustainability performance across villages of varying socio-environmental settings.

The CGRS model provides a robust tool for quantitative analysis, benchmarking, and policy-informed decision-making in rural sustainability measurement through the combination of environmental, infrastructural, and socio-economic indicators into one composite index.

4. Results and Discussion

The results of the study include a demographic breakdown of the three villages' respondents, followed by normalized scores of different parameters.

Table 1. Demographic breakdown of selected villages from survey information

Parameters		Bilashi (%)	Dorli (%)	Padmale (%)
Gender	Male	47	48	56
	Female	53	52	44
Education	Postgraduate	13	14	24
	Graduate	18	35	14
	Secondary	23	18	20
	Primary	21	20	17
	None	24	13	25
Occupation	Housewife	13	13	17
	Farmer	11	17	10
	Retired	18	18	13
	Shopkeeper	16	13	21
	Laborer	21	10	12
	Self-employed	10	18	15
	Teacher	13	13	13
Income	Low	32	41	38
	Middle	31	29	28
	High	38	30	34

4.1. Demographic Results

In Table 1, the demographic breakdown of the three villages' respondents, Bilashi, Dorli, and Padmale, shows a generally balanced gender mix in all sites. In Bilashi, women outnumbered men by a slim margin (53-47%), whereas in Dorli, there was almost parity (52% female, 48% male). Padmale had a higher percentage of male respondents (56%) than female (44%). This balance indicates that the two sexes were satisfactorily covered in the survey so that participative conclusions may be drawn about the people's views. Levels of education differed significantly across the villages.

Padmale recorded the greatest number of postgraduate respondents (24%), with Dorli (14%) and Bilashi (13%) capturing subsequent positions, reflecting greater higher-education representation in Padmale. However, a notable percentage of respondents in every village lacked formal education, especially in Padmale (25%) and Bilashi (24%), capturing the existence of education disparities. Graduate and secondary-level education respondents tended to be more concentrated in Dorli, especially due to localized variation in education. Figure 2 shows a graphical representation of demographic results achieved from the survey.

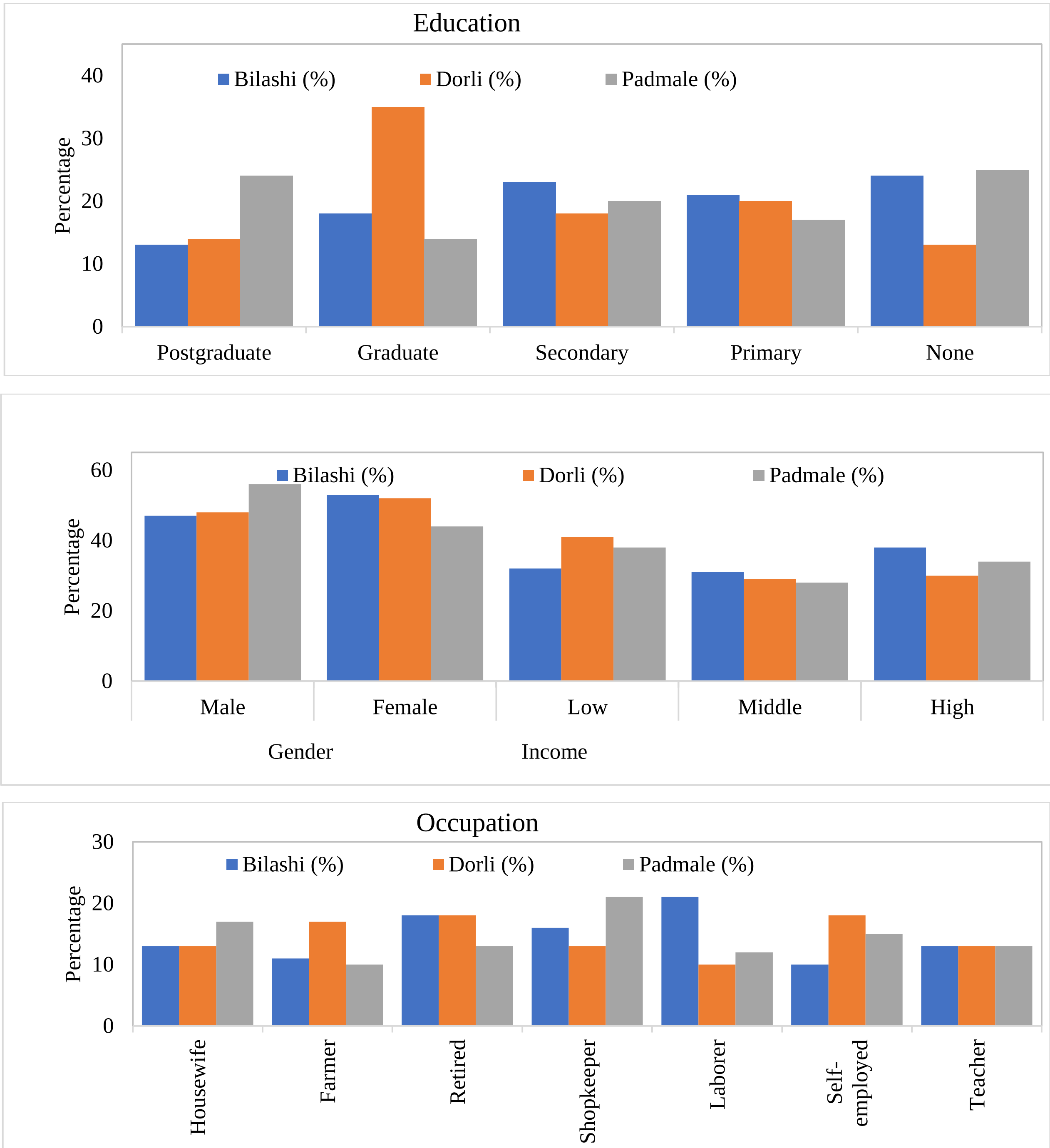

Fig. 2 Graphical representation of demographic results

Occupational trends show a varied economic foundation in the villages. Labourers constituted a significant segment in Bilashi (21%), while farmers were larger in Dorli (17%). Shopkeeping and self-employment stood out strongly in Padmale, with 21% and 15% of the respondents working in these fields, respectively. Housewife and teacher categories were always there across all the villages and implied universal social positions regardless of location.

Distribution of income indicates that low-income families comprised the majority in Dorli (41%) and Padmale (38%), while Bilashi had a more evenly distributed pattern among the low, middle, and high-income categories. The highest income respondents are most likely to be found in Bilashi (38%), representing a relative economic advantage compared to the other villages.

Thus, these population distributions represent a composite picture of gender, education, occupation, and income profiles, which are needed to understand sustainability practice, level of awareness, and community participation in the analyses to follow.

4.2. CGRS of Main Factor Categories

Responses were first given numerical scores according to pre-specified rules of scoring on a standard 0-5 scoring system, which helps in parameter normalization and village normalization objectively. All data were then converted, assigning each respondent a 0-5 score on each of the key parameters in order to enable category-wise means to be compared.

4.2.1. Environmental Parameters

The environmental assessment of the three villages using the Composite Green Rating System detects differences in performance for the set criteria of water management, waste management, and environmental management. The results in Table 2 report scores of environmental parameters categorized into water, waste, and total environmental management. Amongst them, Padmale was best in terms of treated water with a score of 2.83, while Bilashi scored the best regarding water quality with 2.89. Dorli was relatively slow in water quality with an average score of 1.82, and thus indicated the need to improve water-purifying practices there. Scores of water resources uniformly ranged from 2.34 to 2.5 in all villages, indicating moderate use and availability of water resources.

Table 2. Scores of environmental parameters with breakdown of parameters in subcategories

Parameters		Bilashi (0–5)	Dorli (0–5)	Padmale (0–5)
Water Management	Water Treated	2.75	2.46	2.83
	Water Resources	2.36	2.5	2.34
	Water Quality	2.89	1.82	2.37
Waste Management	Waste Collection	2.7	3.4	2.8
	Waste Segregation	2.58	2.46	2.33
	Solid Waste Management	3.48	2.9	3.23
	Composting Done	2.33	2.25	2.42
	Cleanliness	3.56	2.76	3.33
Environmental Management	Rainwater Harvesting	2.25	2.25	1.83
	Vegetation	2.93	2.62	2.72
	Air Quality	2.88	2.7	2.87
	Noise Level	2.98	3.02	3.08
	Average score	2.81	2.6	2.68

Findings of waste management showed that Dorli did better in the collection of waste, with a score of 3.4, while Bilashi did better in solid waste management with 3.48 and overall cleanliness with 3.56, since there was more community involvement in keeping the environment clean.

Generally, composting activities were low across all villages, with scores of between 2.25 and 2.42, indicating possibly an area for improvement within sustainable waste management. The segregation scores of wastes were moderate; the lowest was that of Padmale at 2.33, thus suggesting that systematic waste separation is not yet a common practice.

The environmental management scores point to the relatively balanced performance of villages. The noise pollution was under good control in all areas, and the highest mark went to Padmale at 3.08; rainwater harvesting, on the other hand, received the lowest overall mark, with Padmale at 1.83, indicating extremely low use of this water-saving measure. Vegetation cover and air quality were moderately acceptable in villages, with marks ranging from 2.62 to 2.93. The average marks for environmental CGRS were higher in Bilashi at 2.81, followed by Padmale at 2.68 and Dorli at 2.6, representing the overall better performance of Bilashi with respect to environmental sustainability practices. All in all, these scores show that basic environmental management functions, but targeted interventions in water treatment, composting, and rainwater harvesting are needed for improvements in the sustainability performance of those villages.

4.2.2. Infrastructure Parameters

The infrastructure assessment by CGRS for Dorli, Bilashi, and Padmale focuses on disparities in core amenities and accessibility. Table 3 shows a summary of the infrastructure parameter score per village with respect to sanitation facilities, road type, and distance to health centers.

Table 3. Scores of infrastructure parameters for each village

Village	Has Toilet	Road Type	Health Center Access	Average
Dorli	2.29	3.03	2.62	2.79
Bilashi	2.79	2.88	2.71	2.83
Padmale	2.54	3.03	2.92	2.65

Looking at sanitation, for instance, Bilashi had the highest toilet availability score of 2.79, indicating relatively better sanitation facilities at the household level compared to Dorli and Padmale, which had scores of 2.29 and 2.54, respectively. In terms of road infrastructure, the villages were more or less homogeneous: the connectivity of roads in Dorli and Padmale was rated as quite good, with scores of 3.03 each, while that of Bilashi was rated at 2.88. Access to health centers was considered variable, with Padmale scoring the highest, at 2.92, followed by Bilashi with 2.71 and Dorli with 2.62, reflecting the varying degrees of accessibility of healthcare to the residents. Overall, the average scores for infrastructure were marginally higher in Bilashi at 2.83 and Dorli at 2.79, while Padmale has a slightly lower figure of 2.65, indicating that all villages do have basic infrastructure; however, there is a need for refinement regarding sanitation and access to health centers in Dorli. This indicates that infrastructure development is relatively adequate, though there is room for improvement on aspects where targeted intervention might be undertaken to make access equitably distributed and improve service delivery in all villages.

4.2.3. Sustainability Parameters

In the sustainability assessment, CGRS scores for the villages depict the usage of renewable energy and organic cultivation, with acceptance for undertaking more sustainable practices. Table 4 represents the sustainability scores of the use of renewable energy inputs like biogas as well as solar, the adoption of renewable energy, and organic farming methods.

Table 4. Scores of of the use of renewable energy inputs

Village	Uses Biogas (0–5)	Uses Solar (0–5)	Organic Farming (0–5)	Willing To Adopt RE (0–5)	Average Score
Dorli	2.42	2.83	2.71	2.46	2.61
Bilashi	2.67	2.5	2.17	2.71	2.51
Padmale	2.33	2.71	2.75	2.5	2.57

In Dorli, the highest rating was for solar energy use at 2.83, followed by a moderate use of biogas at 2.42, while organic cultivation received an average 2.71 value for the existing level of sustainable practice. Bilashi recorded higher adoptions of biogas at 2.67 and readiness to adopt renewable energy at 2.71, but was comparatively lower in activity toward organic farming at 2.17, hence presenting potential for increasing sustainable agriculture. In Padmale, the highest rating in organic farming reached 2.75, with a rating of 2.71 in the use of solar energy and 2.33 in the use of biogas. This indicates that the village is increasingly adopting renewable energy as well as sustainable agriculture. All in all, the average ratings of sustainability were not very different from village to village, with Dorli at 2.61, Padmale at 2.57, and Bilashi at 2.51, reflecting a moderate but rising knowledge and use of sustainable practices. From this, it is seen that although renewable energy adoption has commenced, there is a need for more efforts to increase organic farming and expand renewable energy adoption in all villages.

4.2.4. Risk Parameters

Risk assessment of the villages, by CGRS scores, indicates the degree of awareness about environmental, health, and sustainability-related risks among the respondents. Table 5 shows the risk scores, indicating the degree of respondents' risk awareness in every village.

Table 5. Scores of risk parameters for each village

Village	Risk Score
Dorli	2.65
Bilashi	2.68
Padmale	2.66

Bilashi had a slightly superior score (2.68) to Padmale (2.66) and Dorli (2.65), meaning that there is a marginally greater awareness of risks in the community. The fairly similar scores in all the villages indicate that perceptions and knowledge of risks are reasonably consistent, although there is scope to further enhance awareness programs.

These findings suggest that although the villages have a moderate level of risk awareness, focused training and education programs would increase community readiness and proactive action to reduce environmental and sustainability-related hazards.

4.3. Total CGRS Score

The collective sustainability performance of the three villages, measured based on the Composite Green Rating System (CGRS), aggregates environmental, infrastructure, sustainability, and risk ratings. Table 6 gives the total or mean CGRS scores on all parameters assessed for every village.

Table 6. Total CGRS of all parameters for each village

Village	Environmental Score	Infrastructure Score	Sustainability Score	Risk Score	CGRS Weighted Score
Dorli	2.6	2.65	2.61	2.65	2.64
Bilashi	2.81	2.79	2.51	2.68	2.69
Padmale	2.68	2.83	2.57	2.66	2.68

Bilashi was highest in environmental performance with a score of 2.81, and high in risk perception with a score of 2.68. However, its sustainability rating was a notch below at 2.51, which indicates only moderate adoption of renewable technology and organic farming. Padmale fared higher in infrastructure with a value of 2.83, and out of all the other indicators, the scoring was relatively balanced, indicating good basic facilities with medium environmental and sustainability practices. Dorli showed reasonably consistent scores for all parameters, with a lower but moderate environmental performance, a score of 2.6, and a moderate infrastructure, sustainability, and risk score, thus providing an overall CGRS weighted score of 2.64. Overall ratings are: Bilashi 2.69, Padmale 2.68, and Dorli 2.64, which indicate that each village has a moderate level of sustainability performance but with areas of strength, such as Bilashi in environmental management, Padmale in infrastructure, and Dorli with equitable but generally lower overall performance. These observations provide an indicator of areas for further improvement, mainly in optimising sustainability practice and community involvement in the adoption of renewable energy towards higher overall levels of sustainability.

4.4. Village Green Rating

The CGRS rating system classifies the sustainability performance of the villages into four classes: Platinum (4.25–5.00), Gold (3.50–4.24), Silver (2.50–3.49), and Certified (<2.50). Table 7 illustrates the average CGRS score per village, along with the corresponding green rating based on the scoring factors. Accordingly, all three villages - Bilashi, Padmale, and Dorli - based on the integrated evaluation of the environmental, infrastructure, sustainability, and risk parameters, recorded an average CGRS score in the Silver range, with Bilashi rated at 2.69, Padmale at 2.68, and Dorli at 2.64.

Table 7. Average CGRS of all parameters for each village

Village	CGRS Average Score (0–5)	Green Rating
Dorli	2.64	Silver
Bilashi	2.69	Silver
Padmale	2.68	Silver

Bilashi has performed marginally better than the others, primarily due to its strengths in environmental management and risk awareness, while Padmale's strength lies in infrastructure. Dorli shows a relatively balanced performance across all parameters. In essence, a Silver rating points to the fact that the villages at this level are perceived to have moderate sustainability practices concerning functional infrastructure, reasonable environmental management, and moderate adoption of renewable energy and organic farming. Yet, it is open to improvement, especially on promoting renewable energy utilization, improving water treatment and waste management, and increasing the engagement of the community in sustainable practice, in their effort to achieve Gold or Platinum ratings in the future.

4.5. Statistical Analysis

Using green rating parameters, statistical tests were conducted to compare and analyze the sustainability performance in three villages. Tests were designed to establish notable differences, examining the relationship among parameters, and gaining insight into points of intensity at which intervention would have to be enhanced to improve environmental and infrastructure management.

The statistical tests were conducted to compare and analyze the sustainability performance in three villages, using green rating parameters. Tests were intended to create notable differences in addition to scrutinizing the relationship among the parameters. It provides insights into points of intensity at which intervention must be enhanced for improved environmental and infrastructure management.

4.5.1. Kruskal–Wallis Test

It was used to test the disparity in the sustainability scores in the villages for each parameter. The results showed that for all the parameters, such as renewable energy utilization, waste management, and treatment of water, villages did not differ significantly. This points toward relatively even performance levels (Table 8). Some parameters, like sanitation and water quality, had moderate variability, reflecting where specific interventions would be appropriate. The test as a whole makes a fair non-parametric evaluation of inter-village variation in sustainability, both identifying areas of strength and loopholes in environmental as well as infrastructural practice.

Table 8. Performance of system using kruskal–wallis test

Parameter	Bilashi	Dorli	Padmale	Chi-square H	df	p-value	Significance
Water Treated	2.75	2.46	2.83	2.10	2	0.35	NS
Water Resources	2.36	2.50	2.34	0.21	2	0.90	NS
Water Quality	2.89	1.82	2.37	5.32	2	0.07	NS
Waste Collection	2.70	3.40	2.80	2.88	2	0.24	NS

Waste Segregation	2.58	2.46	2.33	0.44	2	0.80	NS
Solid Waste Management	3.48	2.90	3.23	1.12	2	0.57	NS
Composting Done	2.33	2.25	2.42	0.18	2	0.91	NS
Cleanliness	3.56	2.76	3.33	2.12	2	0.35	NS
Rainwater Harvesting	2.25	2.25	1.83	0.52	2	0.77	NS
Vegetation	2.93	2.62	2.72	0.44	2	0.80	NS
Air Quality	2.88	2.70	2.87	0.08	2	0.96	NS
Noise Level	2.98	3.02	3.08	0.06	2	0.97	NS
Has Toilet	2.79	2.29	2.54	1.32	2	0.52	NS
Road Type	2.88	3.03	3.03	0.09	2	0.96	NS
Health Center Access	2.71	2.62	2.92	0.16	2	0.92	NS
Uses Biogas	2.67	2.42	2.33	0.35	2	0.84	NS
Uses Solar	2.50	2.83	2.71	0.38	2	0.83	NS
Organic Farming	2.17	2.71	2.75	1.97	2	0.37	NS
Willing To Adopt RE	2.71	2.46	2.50	0.18	2	0.91	NS
Risk Score	2.68	2.65	2.66	0.01	2	0.99	NS

**NS - Not Significant (p>0.05), df - degrees of freedom*

4.5.2. Spearman Rank Correlation

Spearman's Rank Correlation was utilized in examining the correlations between the sustainability indicators in and among the villages. There were moderate to strong positive correlations, such as between segregation of waste and solid waste management, and between organic agriculture and propensity towards the use of renewable energy (Table 9). These findings indicate that a development in one practice of sustainability is generally followed by the development of other corresponding practices. Overall, the correlation analysis helps in determining correlated parameters, which guide integrated interventions for enhancing the sustainability at the village level.

Table 9. Correlation between parameters using spearman rank correlation test

Parameter 1	Parameter 2	Spearman ρ	Interpretation
Water Treated	Water Quality	0.50	Moderate positive
Water Treated	Waste Collection	0.20	Weak positive
Water Resources	Water Quality	0.30	Weak positive
Waste Segregation	Solid Waste Mgmt	0.90	Very strong positive
Cleanliness	Air Quality	0.60	Moderate positive
Rainwater Harvesting	Vegetation	0.40	Moderate positive
Uses Biogas	Uses Solar	0.10	Very weak positive
Organic Farming	Willing To Adopt RE	0.85	Very strong positive
Road Type	Health Center Access	0.05	Very weak
Noise Level	Air Quality	-0.10	Very weak negative

Spearman's Rank Correlation was applied to determine the correlation between the villages on their environmental, infrastructure, sustainability, risk, and overall CGRS rankings. The pairwise correlation Table 10 indicates that Dorli–Bilashi (ρ = 0.90), Dorli–Padmale (ρ = 0.95), and Bilashi–Padmale (ρ = 0.92) all have very strong positive correlations. These findings suggest that the three villages have very similar sustainability profiles on all parameters evaluated. Although there are slight variations in individual scores, the broader trends of sustainability performance are quite similar across the villages.

Table 10. Correlation between villages using spearman rank correlation test

Village	Correlation (ρ)	Interpretation
Dorli – Bilashi	0.90	Very strong positive correlation
Dorli – Padmale	0.95	Very strong positive correlation
Bilashi – Padmale	0.92	Very strong positive correlation

Statistical comparison gives a wide view of the sustainability performance of the three villages. The result shows that most parameters have no significant differences among villages, which means that most practices are comparatively homogeneous. Parameters like water quality, waste management, and cleanliness are moderately different and might require special attention. High correlations among these parameters are indicated by Spearman's Rank Correlation for good sustainability development. It also enables the statistical analysis necessary for a deeper understanding of variation between villages, identification of the main relationships in sustainability practice, and focused interventions with a view to enhancing overall environmental and infrastructural performance.

4.6. Comparative Analysis

Table 11 presents a comparison of the existing studies, highlighting partial but useful approaches to rural sustainability. For example, Zhang & Tian [27] discuss a structured model of rural evaluation; however, it was limited to governance and environmental indicators with non-quantifiable socio-economic scores. Works like Thomas et al. [25] and Krishnendu et al. [26] have focused on renewable energy and community-based approaches, yet with no unified quantifiable rating. Long-term monitoring, digital governance, and integrated metrics across different domains of rural development also show lacunae from the works of Cuenca-Enrique et al. [17] and Nasution et al. [21].

Table 11. Comparative analysis of existing and proposed methods

Ref.	Key Findings	Values / Metrics Used
Zhang & Tian [27]	Developed an evaluation model for green rural development using structured weighted indicators through AHP.	6 primary and 30 secondary indicators Validation R-value 0.5827–0.8891.
Thomas et al. [25]	Identified gaps between renewable energy interventions and rural livelihood needs using the Energy-Water-Food nexus.	Rural energy consumption 30–50 kWh/month CAPEX of solar pumps ≈ INR 45,000.
Krishnendu et al. [26]	Emphasized participatory rural appraisal and human-centered design for sustainable rural interventions.	Qualitative indicators from two pilot villages Community-centered design insights.
Cuenca-Enrique et al. [17]	Found that rural electrification initiatives lacked long-term monitoring frameworks and sustainability scoring systems.	Review of 90+ studies No unified measurable index reported.
Nasution et al. [21]	Highlighted the convergence of sustainable agriculture, digital governance, and community participation as essential for rural progress.	Bibliometric indicators Conceptual convergence framework with no scoring methodology.
Proposed (CGRS)	Develops a rural-specific Composite Green Rating System integrating water, waste, renewable energy, resilience, infrastructure, governance, and awareness for SDG-aligned evaluation.	Quantitative scoring (0–100) Category weighting model Field survey Certification levels

Contrasting these fragmentary frameworks, the proposed CGRS introduces novelty in the form of offering an integrated and quantifiable 0-100 scoring model by integrating environmental sustainability, infrastructure readiness, livelihood indicators, governance, and SDG alignment. The approach, therefore, makes it measurable and certification-based for conducting benchmarking, comparability across villages, and evidence-based policy intervention regarding the gaps left behind by previous research.

4.7. Discussion

This is novel research that introduces the Composite Green Rating System (CGRS), a quantitative way of capturing village-level sustainability by combining the environmental, infrastructural, social, and risk aspects into one system. The idea behind CGRS is to be a rural-level data-centric and real-time platform that combines the community, attitude, and environmental data and is, thus, more flexible for villages. Therefore, it minimizes the focus on the design and infrastructure characteristics by authors such as the current frameworks, such as the IGBC Green Village Rating.

The article is a major contribution to sustainable rural appraisals as it submits an initial and holistic framework that can be replicated for policy benchmarking and comparative analysis across regions. Additionally, this study is cross-cutting in nature and, therefore, relevant to all the United Nations Sustainable Development Goals (SDGs), but its central focus is SDG 6 (Clean Water and Sanitation), SDG 7 (Affordable and Clean Energy), SDG 11 (Sustainable Cities and Communities), and SDG 13 (Climate Action). The CGRS framework thus places global sustainability ambitions in relation to local reality and, as such, is bridging the gap between grassroots data and policy-level decision-making, which is central to co-creation interventions that are well planned, inclusive, resilient, and sustainable rural communities.

4.7.1. Implications of Score and Policy Relevance

The CGRS scores are significantly different across the three villages in this study. It provides instructive insights into how the environmental context combines with community awareness and resource availability to influence rural sustainability outcomes. High scores in the cases of Padmale and Bilashi indicate that access to natural resources, joined with moderate levels of infrastructure, promotes the use of renewable sources of energy, access to cleaner water, and better sanitation. In contrast, Dorli scored below par because of its exposure to drought conditions, lack of public facilities, and low receipt of renewable energies-all pointers to ecological constraints on growth. Variations such as these underpin the inadequacy of uniform policy frameworks in rural planning, which instead need to be responsive both to locations and to risks. The CGRS framework thus carries value for policymakers eager both to identify priorities for investment, design aptly targeted sustainability programs, and monitor progress in congruence with UN SDGs.

4.7.2. IGBC Green Village Rating System and Composite Green Rating System (CGRS)

The structured approach involves the IGBC Green Village Rating System for rural sustainability. Some of the parameters it looks at include materials and resources, village infrastructure, health and hygiene, water conservation, social and community actions, energy efficiency and availability, and green innovation. It aims to create an eco-friendly approach by facilitating resource optimization, better sanitation, the use of renewable energy, and social participation in sustainability endeavors. The system is, however, fundamentally infrastructural and policy-oriented and is therefore better applicable to planned or partly urbanized rural towns. The new CGRS, on the other hand, has a grassroots, community-based, and data-driven system with built-in direct field-based scoring and perception analysis from the people themselves. It entails not only environmental and infrastructural factors but also sustainable behavior and risk sensitivity, thus offering an integrated view of actual village performance. The envisaged CGRS is thus a simpler, adaptive, human-oriented appraisal tool supportive of actual circumstances and assesses the preparedness of rural people toward sustainable development; it is also more feasible for local-level monitoring and change.

4.7.3. Challenges and Risks of Villages

The comparative performance analysis by CGRS shows various strengths and weaknesses of the specific villages concerning environmental, infrastructural, sustainability, and risk factors. The environmental care sector was where Bilashi performed well, mainly in water quality, which scored 2.89, solid waste disposal with 3.48, and cleanliness with 3.56. The obtained scores replicate a superb set of local sanitation and hygiene. It indicates satisfactory scores of infrastructures, renewable energy use, and organic production at 2.79, 2.51, and 2.51, respectively. In the identical manner, community readiness was observed with the high awareness of the risk score at 2.68. Other things being equal, Bilashi's main challenges are the development of renewable energy use and further improvement of sustainability practices.

Moreover, Padmale has recorded a good infrastructure performance of 2.83. This is evidenced by stable road access and health centers that are adequately equipped, which is important for the well-being of the communities. The ratings for environmental management were good at 2.68, though for rainwater harvesting, it was 1.83, and water quality was rated at 2.37; hence, both were below average. Under the sustainability pillar, practices were mediocre at 2.57, with organic farming being noted as a strong practice at 2.75. The level of risk awareness has been at par with other villages at 2.66. Some of the areas of improvement that water management can consider are improvements in water sources and the adoption of renewable energy.

Dorli's performance indicators were relatively consistent. However, it did not apply to the low environmental scores - 2.6, due to poor water quality - 1.82. Infrastructure and waste management areas received moderate ratings at 2.65, while the application of sustainability practices was at a moderate scale of 2.61, and risk perception at an average of 2.65. The key issues that cropped up from the text are water quality improvement and sanitation, and the use of renewable energy, which has picked up momentum. Overall, the three villages have attained Silver CGRS ratings, which show moderate levels of sustainability performance with relative strengths and weaknesses as reflected in Table 12.

Table 12. Strengths of villages and the challenges and risks in sustainable development

Village	Development Strengths	Risks	Challenges
Bilashi	Strong environmental management, good water quality, and solid waste management	Moderate water scarcity issues, limited renewable energy adoption	Enhance renewable energy use, improve sustainability practices
Padmale	Good infrastructure (roads, health centers), organic farming adoption	Moderate water quality, low rainwater harvesting	Improve water management, increase renewable energy use
Dorli	Balanced infrastructure and sustainability, moderate waste management	Low water quality, sanitation gaps	Improve water treatment, sanitation, and promote renewable energy

4.8. Recommendations for Village Development

In this, villages were recommended based on respective CGRS scores for the purpose of achieving overall sustainability performance. The suggested interventions involve environmental management gaps, sustainable practices, infrastructure development, and increasing awareness in the communities regarding environmental risks. Common themes reflected in these interventions include better water and waste management systems, renewable energy adoption, and active participation of the community in sustainable activities. With such interventions, villages manage to achieve not only improved ratings but long-term environmental resilience as well.

- Recommendations for Bilashi
  - Support rainwater harvesting at the household and institutional levels.
  - Enhance the adoption of renewable energy through solar and biogas installations.
  - Focus on sensitization, training programs, and rewards for the growth of organic farming.
  - Promote the improvement of the waste segregation and composting practices.
  - Enhance sanitation systems in order to achieve full toilet coverage.
  - Provide regular water quality monitoring for a safe and reliable supply.
  - Promote the institute's community programs on environmental conservation and disaster preparedness.
- Recommendations for Padmale
  - Encourage the adoption of RE with the use of solar and biogas energy for homes as well as farms.

  - Increase rainwater harvesting in addition to the improvement of local water treatment facilities.
  - Increase awareness with community-based programs for environmental protection.
  - Enhance the solid waste management and initiate schemes like composting.
  - Focus on reducing the use of chemical fertilizers and encourage organic farming.
  - Focus on enhancing waste segregation systems as well as sanitation infrastructure.
  - Establish standards for the air and noise quality checks to protect the environment.
- Recommendations for Dorli
  - Engage facilities for water storage and treatment for safe water access.
  - Foster clean technologies for utilization in households, including solar power and others.
  - Preserve hygiene through an increase in the waste collection and segregation centers.
  - Enhance public sanitation as well as hygiene facilities with the availability of facilities.
  - Promote programs to enhance sustainable and organic farming.
  - Engage the village in frequent training programs to face disasters with risk management and resilience.
  - Promote the participation of people to empower them in sustainability initiatives.

The interventions proposed here put together a practical set of guidelines for the chosen villages. It guides towards improved environmental quality, sanitation, resource utilization, and infrastructure with the use of renewable energy. Each of the three villages has the potential to move from its current moderate (Silver) sustainability position to a higher one with persistent application of the measures. While improvement does take place in the long run, much indeed depends on sustained awareness generation and positive community participation if improvements are to be lasting. The results obtained from the CGRS rating emphasize the need to institute comprehensive community-based development programs for long-term rural sustainability.

4.9. Urban and Rural Green Rating Systems

In comparing the CGRS for intersectoral rural-urban indicators, extremes in the comparative sustainability performance of the two can be realized. The fact that urban localities score higher is mainly because of the better accessibility to renewable energy facilities, orderly waste management, and water use technologies. Rural settlements such as Bilashi, Dorli, and Padmale are still dependent on conventional sources of energy, have haphazard waste management, and have poor water treatment and recycling facilities, pointing to their interim position in development. The difference is not only in terms of infrastructural and technological deficiencies but also in policy implementation differences, the ability to pay, and the level of awareness of people at the grassroots. Urban communities are enabled by institutionalized actions of sustainability and more solid government systems, while rural communities are empowered at the grassroots, though with limited resources (Table 13). The research shows that there is a need to transfer urban measures of sustainability, in particular, decentralized renewable energy networks, smart waste management systems, and water recycling systems, into rural areas. This will need to be reached with participatory, bottom-up planning and capacity-building for fair progress toward local and global sustainability goals, particularly SDG 6 (Clean Water), SDG 7 (Clean Energy), and SDG 11 (Sustainable Communities).

Table 13. Impact of parameters of GRS on urban and rural analysis

Parameter	Rural Areas	Urban Areas	Key Perceptions
Renewable Energy Use	Limited use of solar and biogas; dependence on conventional sources	High adoption of solar rooftops, energy-efficient buildings, and smart grids	Need to promote decentralized renewable systems in villages
Waste Management Efficiency	Irregular waste collection; limited segregation and composting	Organized waste segregation, recycling, and disposal systems	Rural areas need structured, solid waste management programs
Water Management & Utilization	Low rainwater harvesting, moderate water treatment, and storage systems	Advanced water recycling, sewage treatment, and smart metering	Rural water management requires technological and policy support
Infrastructure & Sanitation	Moderate infrastructure, partial sanitation coverage	Well-developed sanitation, roads, and drainage systems	Strengthen rural infrastructure through eco-friendly planning
Environmental Awareness & Participation	Community-driven but less formalized awareness programs	Institutional awareness campaigns and sustainability education	Encourage participatory rural sustainability programs
Sustainability & Innovation	Emerging practices in organic farming and local green initiatives	Integration of technology, innovation, and policy frameworks	Introduce innovation-based sustainability models in rural areas

CGRS adds value in addressing sustainability dimensions in rural settings that are not captured by urban-focused rating systems such as GRIHA, LEED, and IGBC. While these rating schemes place emphasis on the performance of buildings, infrastructure quality, and urban environmental management, village-specific realities, such as dependence on groundwater, uses of resources, access to energy, and local ecological vulnerabilities, have gone unnoticed. CGRS provides a multi-criteria quantitative scoring model integrated with the rural socio-economic and environmental contexts. The integration of indicators on water security, waste handling, green cover, hygiene, renewable energy adoption, community awareness, and risk resilience parameters aligns directly with SDGs 6, 7, 11, and 14. Hence, CGRS is not just a rating mechanism but also a decision-support framework for policy makers, researchers, and rural development agencies.

Table 14. CGRS comparison with existing urban systems

Aspect	LEED	GRIHA	IGBC	Proposed CGRS
Primary Focus	Energy-efficient building design	Green building assessment	Green village rating (urban-oriented)	Rural sustainability & resilience
Major Parameters	Energy, atmosphere, water, materials	Site, water, energy, materials, comfort	Health & hygiene, infrastructure, energy, resources	Water and waste management, RE adoption, green cover, hygiene, infrastructure, awareness, risk
Context Orientation	Urban & industrial	Urban institutional/large campuses	Urban village settlements	Rural households, livelihood & ecosystem-based parameters
Unique Features	Integrative design & energy optimization	Human comfort & energy efficiency	Green innovation & community actions	Risk resilience (drought, flood, erosion), livelihood-linked indicators
Scoring Method	Points-based (Certified–Platinum)	Star rating (1–5)	Level-based (Certified–Platinum)	Composite 0–100 score; 4-tier rating (Certified–Platinum)
Applicability	Global urban settings	Indian buildings	Semi-urban/urban villages	Fully rural, climate-vulnerable, and resource-scarce regions

5. Conclusion

The study designs and implements a CGRS to measure rural village sustainability performance in terms of multi-dimensional measures of environmental, infrastructure, sustainability, and risk factors. The results showed that all three rural villages of Bilashi, Padmale, and Dorli were of Silver rank, showing modest improvements in sustainable rural development. Bilashi ranked top in environmental management and sanitation, Padmale ranked top in infrastructure and organic farming, and Dorli was well-balanced but weaker across the board. They quote that while there are already platforms for sustainability, there are immense opportunities for improvement through increased use of renewable energy, efficient waste and water management systems, and increased awareness among the population. Fostering participatory governance, embracing eco-friendly technology, and enhancing access to green infrastructure can go a long way towards boosting these villages' sustainability standing. CGRS emerged as an effective way to assess and compare the sustainability at the village level. This helped policymakers with one actionable and responsive tool for flagging priority areas and designing targeted green growth strategies for rural areas.

Although extensive, the research was limited by sample size and the number of villages being analyzed and, therefore, may not be representative of broad regional disparity. The CGRS also relied to some extent on self-reported data, which might have introduced subjectivity in response. Certain parameters, such as long-term environmental impact and socio-economic forces, were not fully assessed either due to data constraints. In the future, the model can be expanded to embrace more villages, include remote sensing and IoT-based environmental monitoring, and use enhanced data analytics for more accurate and real-time estimation of sustainability. This will enhance the robustness, scalability, and usability of the CGRS framework for planning at the regional and national levels for sustainability.

Ethical Considerations

Informed consent regarding the purpose of the research was sought from all the participants, and written consent was obtained before data collection.

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