

# Article

# A Comprehensive Measurement of Progress toward Local SDGs with Geospatial Information: Methodology and Lessons Learned

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Abstract: The UN's 2030 Agenda defined 17 Sustainable Development Goals (SDGs). In order to ensure the implementation of this global agenda, the UN proposed a systematic follow-up and review through indicator-based tracking and reporting of the progress with statistical and geospatial information toward SDGs at national, regional, and global levels. This has posed many technical and institutional challenges. Although international communities have devoted great attention to this hot topic, most of their work has focused on the conceptual design and preliminary testing. There are very few good practices for a comprehensive measurement and assessment of progress toward SDGs with the integration of statistical and geospatial information at national or local levels. This paper presents the methodology and results of a pioneer project which measured the progress toward SDGs at a local level in China (i.e., Deqing County) by integrating statistical and geospatial information. In this study, a number of technical/institutional issues have been tackled, such as the adoption of appropriate indicators at a local level, availability and acquisition of reliable data sets, and spatiotemporal analysis with a geographical perspective, interaction between SDGs and cross-sector coordination. The major conclusions are (a) the comprehensive progress toward SDGs in Deqing can be most appropriately measured and assessed by integrating geospatial and statistical information; (b) Deqing has made significant economic and social advances while maintaining a good ecological environment over the past few years. The results were released at the first United Nations World Geospatial Information Congress as a good practice and a live example to stimulate discussions.

**Keywords:** 2030 Agenda; Sustainable Development Goals (SDGs); geospatial information; indicators; measurement

# 1. Introduction

The United Nations 2030 Agenda for Sustainable Development (hereinafter referred to as the 2030 Agenda) set up 17 Sustainable Development Goals (SDGs) and 169 targets, aiming to end poverty and promote prosperity and people's well-being while protecting the environment by 2030 at national, regional, and global levels [1]. In order to ensure successful implementation of this global agenda, the United Nations called upon a systematic follow-up and review of the progress toward SDGs [2,3] in



accordance with a SDGs Global Indicator Framework (hereafter called SGIF) [4], which was developed by the Inter-Agency and Expert Group on SDG Indicators (IAEG-SDGs) [5]. The SGIF consists of more than 230 indicators, with at least one indicator for each of the 169 targets. The measurement of these indicators and the progresses toward SDGs places significant demands on timely, reliable, and disaggregated data with a number of specific requirements, including geospatial dimensions [6–9].

Efforts have been devoted to the measurement and monitoring the progress toward SDGs during the last few years. At global and regional levels, the Sustainable Development Solutions Network (SDSN) used statistical data from the World Bank database to assess SDGs baselines for 149 countries with reference to the SDG index and dashboards [10,11]. The United Nations Economic and Social Commission for Western Asia (UN-ESCWA) measured the progress toward SDGs in 22 countries of the Arab region with the help of 20 years of statistical data [12]. Researchers from South Africa used the statistical databases of World Bank and the UN Food and Agriculture Organization (FAO) to assess the agricultural sustainability in Southern Africa [13]. At a national level, progress and priorities for the SDGs were also assessed in Australia and China [14,15]. At a subnational level, such studies are not rare [15,16]. However, there is a common problem associated with these studies, i.e., only making use of statistical data but not of geospatial information. This leads to difficulties in describing geographic patterns, revealing regional differences, and exploring spatiotemporal effects of SDGs practices, because many SDGs, targets, and indicators have a geographic nature.

It is therefore imperative to harness geospatial information in measuring and monitoring the progress toward SDGs [17–19]. In 2017, the Working Group on Geospatial Information of the IAEG-SDGs was established (named as IAEG-SDGs: WGGI) to explore the role of geospatial information and promote its utilization in SDGs monitoring [20]. They identified more than 20 SDGs indicators which could be derived directly or indirectly with geospatial information [21,22]. The Group on Earth Observations (GEO) launched an initiative "Earth Observations for Sustainable Development (EO4SDG)" (http://eo4sdg.org/) and organized a series of workshops and capacity-building activities [23]. In 2019, the Chinese Academy of Sciences held a press conference in Beijing on the report of Earth Big Data Supporting Sustainable Development Goals. This report cites 12 typical cases centered on 11 SDG indicators of five selected SDGs (SDG2, 6, 11, 14, 15) which could be derived directly or in-directly with geospatial information [24]. Nowadays, there is a growing number of publications regarding the utilization of geospatial information and earth observation in SDGs measurement and monitoring [23–26]. However, most of them have discussed only a single or a few indicators [27–29], or a single goal or target [30–33]. Thus, these studies are not capable of providing an overall picture regarding the achievement of sustainability goals.

The 2030 SDGs was defined as an "indivisible whole" embracing three pillars, i.e., economic prosperity, social inclusion, and environmental protection [34,35]. In order to provide an overall picture regarding the distance from achieving the 2030 SDGs, a holistic performance evaluation of all goals and targets should be realized by a comprehensive measurement and with an integrated utilization of geospatial and statistical information [8,36]. To address this challenge, a pilot study was conducted by the authors in Deqing county of the Zhejiang Province, China [37]. It aimed to answer two basic questions: (1) How can the overall progress toward the SDGs at a local level be measured in alignment with the United Nations SGIF through integration of geospatial and statistical information? (2) How far is the county from achieving 2030 SDGs? To complete such a project, a number of technical problems needed to be solved, including the adoption of appropriate sets of indicators covering all the three SDG pillars, the preparation and provision of reliable and ready-to-use geospatial data, the calculation and analysis of SDGs indicators and goals (and targets) with a geospatial lens, and the overall evaluation of the sustainability performance.

This paper presents the overall methodology and major outputs of this pilot research project. Section 2 summarizes the overall methodology, which is characterized as SGIF-aligned, data-driven, and evidence-supported. Section 3 describes how a set of 102 local indicators were selected through a localization analysis of SGIF and how they were calculated with a geospatial lens. An evidence-based,

three-level assessment and its results are provided in Section 4. Further research issues are discussed in Section 5.

## 2. Methodology

A comprehensive SDGs progress measurement in a local context depends critically on how to adopt/adapt adequate indicators in alignment with the SGIF and covering its major sustainable development aspects, whether reliable geospatial and statistical data are available, how to measure the indicators in support of geospatial information, and what quantitative and qualitative evidences can be used to assess the progress [38]. The methodology is summarized and illustrated by Figure 1, which is characterized as indicator-based, data-driven, and evidence-supported.



**Figure 1.** Methodology for a comprehensive measurement of progress toward Sustainable Development Goals (SDGs).

(1) SGIF-Aligned Indicator Adoption

The United Nations SGIF was taken as a starting point of the adoption of adequate indicators. The alignment with SGIF enables an international comparison [12]. Since the SGIF was designed originally from global perspective, it may not meet all the requirements of a local SDGs study. In order to tailor it to local circumstance, three criteria were proposed for performing a localization analysis, i.e.,

- Adaptability: Referring to the analysis of whether each indicator of the Global Indicator Framework has a practical significance for the local context or adapts to the local development priorities;
- Comprehensiveness: Meaning that the selected indictors should cover the major aspects of local SDGs;
- Measurability: Used for determining whether each selected indicator can be quantified with reliable geospatial and statistical data.

After such an analysis, it was found that many indicators could be adopted directly from the SGIF, but some others might be subject to necessary extension, revision, or substitution.

(2) Spatiotemporal Data Processing

To generate reliable data sets with desired spatial and temporal resolution, geospatial disaggregation, change mapping, and other spatiotemporal processing were carried out.

# (3) Data-Driven Indicator Calculation

Three different methods were used for calculating or deriving the selected indicators from geospatial and statistical data sets. The first was to derive indicators directly from geospatial data (including remote sensed imagery) using spatial density calculation, land-cover classification, and others. The second calculated indicators directly from statistical data through ratio (or proportion), rate of change, index, or other calculations. The third one utilized both statistical and geospatial data with the help of quantitative measurement of spatiotemporal accessibility, coverage, relations, and others.

utilized multitemporal remotely sensed data to extract the changes of wetlands, forest, and built-up areas and generated time-series data, which were the basis for calculating indicators and assessing

SDG goal(s) assessment with a geographical location perspective [40,41].

# (4) Evidence-Supported Progress Assessment

The quantified indicators, multitype facts (data and local practices), and other evidences were used to assess the progress toward SDGs at three different levels. First, every indicator was aligned with internationally and/or nationally recognized criteria or references (see Section 4.1) and then given a rank with four grades. Second, each local SDG was assessed through a focused analysis on the achievement and characteristics, as well as existing problems. Last, three SDG clusters (i.e., economy, environment, and society) were analyzed, respectively, to derive an overall picture of the economic growth, social inclusion, and natural beauty, as well as their coherency.

# (5) Study Area

The pilot study area was Deqing County, which is located in the northeast part of the Zhejiang Province, P. R. China (Figure 2), with an area of 936 km<sup>2</sup> and a population of about 440,000. It belongs to the Yangtze River Delta, and the subtropical humid monsoon climate creates four clear seasons with warm and humid weather, and annual average temperature of 17.2 °C. With a topography higher in the west and lower in the east, its land cover can be characterized as "50% mountain, 10% water and 40% farmland", forming a livable place with mountains in view and waters in sight. The county is adjacent to the north of Hangzhou and to the west of Shanghai and takes only 13 min to Hangzhou from Deqing by high-speed train, and less than 2 h by car to most major cities in the Yangtze River Delta region (such as Shanghai, Ningbo, and Nanjing). Deqing County has a long tradition in practicing the concepts of sustainable development and has a solid foundation of geospatial and statistical information.



Figure 2. Geographical location of Deqing County (extracted from Google Maps).

## 3. Comprehensive Measurement of SDGs with a Geographic Lens

## 3.1. Adoption of 102 Indicators with an AERS Strategy

In Section 2, it was pointed out that the SGIF was designed for measurement at a national level, and a localization analysis was provided to tailor the SGIF to local circumstance. In this study, an AERS (Adoption, Extension, Revision, and Substitution) strategy was developed for the localization of indicators. In the end, a set of 102 indicators were adopted for assessment, as shown by Table 1.

| SDG   | Num. of SGIF Indicators | Num. of Deqing Indicators | Indicators   |
|-------|-------------------------|---------------------------|--|
| 1     | 14                      | 5                         | 1.1.1; 1.3.1; 1.4.1; 1.a.2; 1. b.1                             |
| 2     | 13                      | 9                         | 2.1.1; 2.1.2; 2.2.1;2.2.2; 2.3.1; 2.3.2; 2.4.1; 2.a.1; 2.c.1   |
| 2     | 27                      | 15                        | 3.1.1; 3.1.2; 3.2.1; 3.2.2; 3.3.1; 3.3.2; 3.3.3; 3.3.4; 3.4.1; |
| 3     |                         |                           | 3.6.1; 3.7.1; 3.8.1; 3.b.1; 3.b.2; 3.c.1                       |
| 4     | 11                      | 7                         | 4.1.1; 4.2.2; 4.3.1; 4.5.1; 4.6.1; 4.a.1; 4.c.1                |
| 5     | 14                      | 4                         | 5.1.1; 5.5.1; 5.5.2; 5.c.1                                     |
| 6     | 11                      | 7                         | 6.1.1; 6.2.1; 6.3.1; 6.3.2; 6.4.1; 6.4.2; 6.6.1                |
| 7     | 6                       | 3                         | 7.1.1; 7.1.2; 7.3.1  |
| 8     | 17                      | 6                         | 8.1.1; 8.2.1; 8.5.2; 8.6.1; 8.9.1; 8.9.2                       |
| 9     | 12                      | 9                         | 9.1.1; 9.1.2; 9.2.1; 9.2.2; 9.3.1; 9.5.1; 9.5.2; 9.b.1; 9.c.1  |
| 10    | 11                      | 2                         | 10.1.1; 10.2.1   |
| 11    | 15                      | 9                         | 11.1.1; 11.2.1; 11.3.1; 11.4.1; 11.5.1; 11.5.2; 11.6.1;        |
|       |                         |                           | 11.6.2; 11.7.1;  |
| 12    | 13                      | 5                         | 12.2.2; 12.4.2; 12.5.1; 12.6.1; 12.7.1                         |
| 13    | 8                       | 4                         | 13.1.1; 13.1.3; 13.3.1; 13.3.2                                 |
| 15    | 14                      | 7                         | 15.1.1; 15.1.2; 15.2.1; 15.3.1; 15.4.1; 15.4.2; 15.a.1         |
| 16    | 23                      | 5                         | 16.1.1; 16.1.3; 16.3.2; 16.5.1; 16.6.1                         |
| 17    | 25                      | 5                         | 17.1.1; 17.2.1; 17.3.1; 17.8.1; 17.11.1                        |
| Total | 234                     | 102                       |  |

Table 1. The 102 indicators used for the Deqing study \*.

Note: \* The table is the result of the localizing indicators using an Adoption, Extension, Revision, and Substitution (AERS) strategy from the SDGs Global Indicator Framework (SGIF). The details of the 102 indicators can be found from our website: http://www.deqing-sdgs.cn/Download.aspx?language=en.

- Adoption means that the original indicator, including metadata (the indicator name, definition, and calculation method), was not changed. An example is indicator "3.2.1: Under-five mortality rate". The definition is same as the statistical yearbook [42] and the numerical values can be used directly. There were 47 indicators of this type (i.e., adoption).
- Extension means that the name, definition, and calculation method of the original indicator were basically applicable, but the connotation or calculation method was extended somehow. There were six indicators in this category. An example is indicator "6.6.1: Change in the extent of water-related ecosystems over time". Based on its definition, it was extended into four sub-indicators to quantitatively describe this indicator, i.e., (a) rate of change in the spatial extent of water-related ecosystems; (b) rate of change in the water quantity characteristic of water-related ecosystems; (c) rate of change in the water quality of water-related ecosystems; (d) health status of the typical wetland ecosystem.
- Revision was to modify the calculation method of the indicator in order to better satisfy the needs
  of local SDGs monitoring. Forty-two indicators were revised. An example is indicator "3.8.1
  Coverage of essential health services". The original definition contained multiple aspects which
  were too complicated for a county. Therefore, the definition was revised to how fast people can
  access health services with geospatial view.
- Substitution took place when the original indicator was not applicable. In this case, a new indicator
  was proposed. Seven indicators were substituted. An example is indicator "2.3.2: Per capita
  disposable income of rural residents". The original indicator was the average income of small-scale
  food producers by sex and indigenous status with no metadata, which was substituted according
  to the local characteristics.

These indicators provided a full cover of all 16 SDGs, except the Goal 14 "Life Below Water", which is related to ocean, as Deqing is an inland county. This ensured a comprehensive measurement and analysis of the progress toward SDGs. Metadata were developed for each of the 102 indicators, including their definition, calculation method, and data requirements.

## 3.2. Geospatial Di-aggregation and Change Mapping

More than 200 types of statistical and geospatial data were collected in this case study. The main source of statistical data was local authoritative publications, such as the County Annual Statistical Bulletin, County Government Work Report, and the Water Resources Bulletin. The fundamental geospatial data were collected from the Deqing Geographic Information Centre, including vector data, digital elevation model (DEM), land cover, and remote sensing images.

The original population census data were collected for each administrative unit. As there are only 12 towns in Deqing, the spatial variation details of population are largely smoothed, making it difficult to examine its geographic distribution and pattern (Figure 3a). In this study, population was estimated according to heights and sizes of buildings, and population density at 30-m spatial resolution was then generated [39,43,44]. The results of the geospatially disaggregated population density are given by Figure 3b, where more spatial details about the population distribution pattern can be observed. It will serve as an important data set for measuring indicators and goals with a geospatial lens.



**Figure 3.** Geospatial disaggregation of population census data. (**a**) Administrative unit-based population data; (**b**) 30-m population density with topographic information.

Multitemporal remotely sensed images were used for land cover change mapping. For instance, Landsat images over last 30 years were collected and processed to derive wetland changes of Xiazhu Lake, the major wetland park of the county. Based on long-term Landsat satellite data, considering different types of water bodies and different meteorological conditions, a long-term series water sample

library was established. According to the characteristics and needs of different regions, the sample library was automatically matched according to certain rules, and machine learning algorithms (such as random forest) were used to achieve fast and automatic extraction of long-term water resources information. Figure 4a gives the results of wetland changes in dry seasons and wet seasons, which are fundamental data for SDG 6 and indicator 6.6.1. Figure 4b,c illustrate, respectively, the mapping results of built-up areas and forest of the county.



**Figure 4.** Change mapping with multitemporal remotely sensed images. (**a**) Wetland change (1984–2017); (**b**) change of build-up area (1990–2015); (**c**) forest change (2013–2017).

Similarly, the change information of forest and built-up areas for Goals 11 and 15 was derived from multitemporal image data sets. For instance, from 2012 to 2017, the total forest coverage extracted from Landsat images remained stable at over 40% in Deqing County [41]. However, owing to the constructions of upscale homestay and road, the forest covers in some areas slowly declined, such as the Mogan Mountain, which is a famous tourist attraction in China and an ecologically sensitive area (Figure 4c).

## 3.3. Measuring Local Indicators with a Geospatial Lens

With the ready-to-use data, the 102 indicators were measured in three different ways. Eighty-six indicators were computed from statistical data, and 16 indicators were derived with the help of geospatial information, as shown in Table 2. Among them, nine indicators (e.g., 6.6.1, 15.1.1) were derived from geospatial data, and the remaining seven indicators (e.g., 11.3.1, 3.8.1) were measured by integration of statistical with geospatial data. It should be noted that different sub-indicators (indices) for a compound indicator may be computed in very different ways. For instance, 9.1.1b (Road density) was derived directly from road network data, but 9.1.1a (Proportion of rural population living within 2 km of an all-season road) was derived through the combination of geospatial (road network) and statistical data (population).

Figure 5 gives an example of how to derive indicator 1.4.1 with the combination of geospatial and population density data. Spatial accessibility was computed on the basis of disaggregated population density with 30-m resolution. Based on the urban road network data and the distribution data of basic service, a road network analysis model was established to calculate the convenience of basic

service. Finally, combined with the population density, the evaluation result with "spatial and temporal coordinates" was formed, and the index calculation result was dynamically expressed.

| No |        | Indicator  | Type <sup>1</sup> |
|----|--------|--|-------------------|
| 1  | 1.4.1  | Population and proportions living in households with access to basic services  | А                 |
| 2  | 2.4.1  | Proportion of agricultural area under productive and sustainable agriculture   | В                 |
| 3  | 3.8.1  | Coverage of essential health services  | А                 |
| 4  | 6.2.1  | Proportion of population using safely managed sanitation services  | А                 |
| 5  | 6.3.2  | Proportion of bodies of water with good ambient water quality  | В                 |
| 6  | 6.6.1  | a Change in the extent of water-related ecosystems over time<br>d Health status of the typical wetland ecosystem                   | А                 |
| 7  | 9.1.1  | a Proportion of rural population living within 2 km of an all-season road<br>b Road density<br>c Weighted average travel time      | А                 |
| 8  | 11.2.1 | Proportion of population that has convenient access to public transport, by sex, age and persons<br>with disabilities              | А                 |
| 9  | 11.3.1 | Ratio of land consumption rate to population growth rate   | А                 |
| 10 | 11.7.1 | Average share of the built-up area of cities that is open space for public use for all, by sex, age, and persons with disabilities | В                 |
| 11 | 15.1.1 | Forest area as a proportion of total land area   | В                 |
| 12 | 15.1.2 | Proportion of important sites for terrestrial and freshwater biodiversity covered by protected areas,<br>by ecosystem type         | В                 |
| 13 | 15.2.1 | Proportion of forest change  | В                 |
| 14 | 15.3.1 | Proportion of land that is degraded over total land area   | В                 |
| 15 | 15.4.1 | Protected area coverage of import. sites for mountain biodiversity   | В                 |
| 16 | 1542   | Mountain vegetation cover  | в                 |

Table 2. The 16 indicators derived using geospatial data.

Note: <sup>1</sup> Type A means calculating by combined statistical and geospatial data, type B is only using geospatial data.



Figure 5. Deriving indicator 1.4.1 with a geospatially disaggregated data.

# 4. Comprehensive Assessment of SDG Indicators at Three Levels

# 4.1. Ranking of Indicators

The indicators were aligned with the international or national benchmarks (recognized criteria or references) and were ranked by a four-score scheme, with a color for each score. The first rank was green, meaning basically fulfilling the requirements of the indicator; the second rank was yellow, standing for being upgraded; the third rank was orange, which demonstrated facing challenges; and the bottom rank was red, showing the result was far from achieving the 2030 indicator requirements. Table 3 takes SDG 6 as an example and demonstrates how its seven local indicators were ranked.

# Table 3. Calculating and ranking SDG 6 indicators.

| Indicators  | Quantitative Result  | Evaluation Reference  |    |
|---|--|---|----|
| 6.1.1 Proportion of population using safely managed drinking water services   | Urban: 100%<br>Rural: 99.6%  | Green: ≥98%   | I  |
| <b>6.2.1.a</b> Penetration rate of sanitary toilets in rural areas <b>6.2.1.b</b> Service convenience of urban public toilets | 98%<br>From all parts of town, the nearest public toilet can be reached within 16 min            | Green: ≥95%   | Ι  |
|   | Urban domestic sewage: 91.06%  | Municipal domestic sewage: 92.4%;   | IV |
| 6.3.1 Proportion of wastewater safely treated   | Rural domestic sewage: 80.68%  | Coverage rate of the treatment of domestic wastewater (upper-middle-income countries):59% | ш  |
|   | Trade effluent: N/A  |   |    |
| 6.3.2 Proportion of bodies of water with good ambient water quality   | 68.75%, 100% **  | 76.9%   | IV |
| 6.4.1 Change in water-use efficiency over time  | The water consumption per 10,000 CNY of GDP in 2017 was 65.7 $\rm m^3,$ dropped 23.52% from 2015 | By 2020, the efficiency of water use will be 23% lower than that of 2015                  | п  |
| <b>6.4.2</b> Level of water stress: freshwater withdrawal as a proportion of available freshwater resources                   | 25.08%   | Green: ≤25%<br>Yellow: 25% < x ≤ 50%  | I  |
| 6.6.1 Change in the extent of water-related ecosystems over time  | 6.47%  | 0–20%: Highly sustainable;  |    |
| 6.6.1.a Rate of change in the spatial extent of water-related ecosystems  | 11.14%   | 21–40%: Locally sustainable but threatens global stability;                               | ш  |
| 6.6.1.b Rate of change in the water quantity characteristic of water-related ecosystems                                       | 8.26%  | 41-60%: Border-line sustainability. Corrective actions are strongly recommended;          | ш  |
| 6.6.1.c Rate of change in the water quality of water-related ecosystems   | 0%   | 61–100%: Unsustainable Urgent renewal is required.  |    |
| 6.6.1.d Health status of the typical wetland ecosystem  | Xiazhu Lake wetland: In good condition   |   |    |

Note: The data in the table is 2016 data, except for \*\* represents 2017 data. Metrics used for Comparing/ranking: I—SDGs Dashboard; II—National plan; III—Multiple evaluation;

IV—Others. Ranking Class: 📕 1st Quarter 🧧 2nd Quarter 🔲 No ranking.

The results of indicators 6.1.1, 6.2.1, and 6.4.2 were compared with the SDG indicator thresholds in the SDGs Index and Dashboard [45], which is an international benchmark released by the Bertelsmann Foundation and the United Nations Sustainable Development Solutions Network (SDSN). It was derived from the results of 157 UN member states/regions by adjusting most indicators to the score range between 0 (lowest) and 100 (highest), and was marked as the reference category "I". The indicator thresholds are the same for all countries and were subject to extensive consultations with expert communities [45]. For instance, Green of SDG 6.4.2 (Level of water stress: freshwater withdrawal as a proportion of available freshwater resources) in the indicator thresholds was less than 25%, and yellow was between 25% and 50%. The result of water stress in Deqing was 25.08%. Thus, the SDG6.4.2 was ranked as yellow.

The National Plan is the major nationally recognized benchmark, which defines a set of qualitative and quantitative requirements to be achieved by 2020 and 2030, respectively, and was marked as the reference category "II". For instance, the indicator threshold of SDG 6.4.1 was not available in the SDGs Index and Dashboard. Thus, a quantitative national criterion derived from the National Plan was adopted, which states that "by 2020, reduce the water consumption per CNY ¥10,000 of GDP by 23% from 2015" [46]. Deqing reduced water consumption by 23.52% in 2017. Thus, the SDG 6.4.1 was ranked as green.

In case of lacking international and national criteria, the world's advanced level and average level of a given indicator was used for comparison and assessment. It was marked as the reference category "III". For instance, SDG 6.6.1 relates to the spatial extent, water quantity, and water quality of the water-related ecosystems, and was calculated by the weighted averaging of the three categories. The extent to which the water-related ecosystem deviated from its natural state was 6.47%. The SDG 6.6.1 was ranked as green through the comparison of the result and Ecological Classes, which was proposed by UNWATER and Kleynhans [47,48].

It should be noted that no appropriate benchmarks (references) were found for 23 indicators, such as the "Health state of the typical wetland ecosystems" of indicator 6.6.1. Such indicators were marked "gray" in Table 3. In addition, the "trade effluent" of indicator 6.3.1 was marked "gray" because of the unreliable and inconsistent data.

In total, 79 of the 102 indicators had comparable reference or criteria. Among them, 68 reached or almost reached the objectives of the United Nations Agenda 2030, as well as ranking top in China and even in the world (green). Nine indicators needed to be improved, and two indicators faced challenges.

#### 4.2. Evaluation of Individual Goals

In order to derive meaningful assessment results, the original numerous targets of each SDG need to be grouped into 2 to 4 sub-sets with clearly implied meaning (or connotation), which can be considered as local targets. The evaluation or assessment of each SDG will be facilitated through a focused analysis of these local targets with the help of the quantified indicators, and other spatio-temporal evidences, such as multi-temporal images and maps, local knowledge and experiences. For instance, the original SDG 6 aims to "Ensure availability and sustainable management of water and sanitation for all", and has eight targets (https://www.un.org/sustainabledevelopment/water-and-sanitation/). It covers a number of topics ranging from drinking water (6.1) and sanitation (6.2), water quality (6.3) and water use efficiency (6.4), water resource management (6.5), protecting water-related ecosystems (6.6), international cooperation and capacity-building in water- and sanitation-related activities (6.a), as well as involvement of local communities (6.b). According to the local circumstance of Deqing County, they were grouped into three local targets with a clear connotation, i.e., safe drinking water and sanitation, water resources utilization and protection of water-related ecosystems (Figure 6).

"Safe drinking water and sanitation" focuses on equitable access to safe drinking water and sanitation services for all, including the provision of household piped water supplies rate and sanitary toilet services in rural, urban and public places. With the indicators 6.1.1 and 6.2.1, it can be observed that a full coverage of safely managed drinking water and sanitation service have been achieved

through strictly implementing water environment function zoning and protecting drinking water source in the past years. After feces decontamination, the penetration rates of sanitary toilets in urban and rural areas reached 100% and 98% respectively. Now all the urban residents can get access to public toilets in 16 min.



Figure 6. Assessment of local SDG 6 with spatiotemporal evidence.

"Water resources utilization" refers to water quality and water use efficiency, including water resources management, including total water resources, good water standard-reaching rate, water use efficiency, and water shortage pressure. With the integrated analysis of indicators 6.3.1, 6.3.2, 6.4.1, and 6.4.2, it can be shown that the total amount of water consumption has been well controlled through the strictest water resources management mechanism. The water quality of Deqing improved gradually from 2013 to 2017, and the water quality of all 34 major rivers in 2017 reached standard through wastewater treatment in urban and rural treated areas, shutting down the polluting aquaculture and industries with ecological compensation mechanisms, and rectifying the high-water consumption industries, such as printing and dying, papermaking, and the chemical industry. The efficiency of water utilization increased by 47.7% from 2012 to 2016 through the construction of a water-saving society and by controlling pollution in agriculture and industrial areas.

"Protection of water-related ecosystems" focuses on the function change of water-related ecosystem over time (6.6.1), analyzing the sustainability of water-related ecosystem through the area, quantity, quality, and health status of the water-related ecosystem. With multitemporal imagery and statistical data, the extent to which the water-related ecosystem deviates from its natural state was estimated as 6.47% in the past 35 years. This means that the water-related ecosystem has been protected effectively. Indeed, the 10 sub-indicators related to water ecosystems (e.g., wetland water quality, water source assurance rate, soil heavy metal content, soil moisture content, biodiversity) have been comprehensively improved. For example, the soil conditions, water environment, and biodiversity/habitat of the Xiazhu Lake National Wetland Park, which is the largest natural wetland ecosystem in Southern China, are well maintained.

According to the comprehensive analysis of "Safe drinking water and sanitation", "Water resources utilization", "Protection of water-related ecosystems" and other relevant evidences or facts, the following were found: The full coverage of safely managed drinking water has been achieved, the proportion of good-quality water in the 34 major rivers had increased from 13.3% in 2013 to 100% in 2017, and the health conditions of the water-related ecosystems have been greatly enhanced. However, in view of the current level of water stress, the county still a certain degree of potential water shortage.

Based on the above quantitative evaluation of indicators, a single goal was ranked according to the principle of "minimum factor", and the degree of realization of each goal was determined by the degree of realization of the lowest indicator in the goal. In this case, the SDG 6 was ranked as the second class (as yellow, need to be improved), as shown by Figure 7. In total, eight SDGs reached standard (green), six SDGs needed improvement (yellow), and only two SDGs (SDG 11 and SDG 17) faced challenges (orange). There was no significant gap between Deqing's goals and that of the 2030 Agenda (no red).



Figure 7. Assessment result of all the 16 individual SDGs in Deqing.

# 4.3. Evaluation of Goals in Three Clusters

All the major SDGs were grouped into three clusters—environmental, economic, and social—according to the contribution or relevance of their indicators, as shown in Figure 8. The economic cluster included five SDGs (Goal 2, 7, 8, 9, and 10). The environmental cluster included five SDGs (Goal 6, 12, 13, 14, and 15). The social cluster includes 12 SDGs (Goal 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, and 16). It should be noted that a single SDG may be allocated to two or three goal clusters. For instance, SDG 2 and SDG 8 were grouped into both the economic and social cluster, and SDG 6 was grouped into both the social and environmental cluster. SDG 7 fell into all the three clusters due to the contribution of their individual targets or related indicators.



Figure 8. Three goal clusters and their affiliated targets.

A set of key elements or analysis priorities were further defined for each SDGs cluster. For instance, the analysis of the economic SDGs cluster focused on economic growth conditions, economic growth trends, and economic development. For the environmental SDGs cluster, the analysis focused on resource use, ecological environmental protection, and regional responses to climate change. For the

social SDGs cluster, analysis focused on how the three basic needs (survival, security, and development) are met.

Figure 9 explains how the focused analysis was implemented for the environmental goal cluster. The rational utilization of resources was analyzed though energy efficiency, water resources improvement, efficient use, and water-related ecosystems protection. Ecology and environment were analyzed through pollution prevention, green consumption, sustainable management of forests, measures for curbing land degradation and biodiversity conservation, and effects of human protection of ecological environment. Human regional response to climate change was analyzed through the ability of disaster resilience and the penetration of awareness.



Figure 9. Focused analysis of environmental SDGs cluster in Deqing.

SDGs are integral and inseparable. The good coordination within each SDG cluster and among three SDG clusters is an important sign to measure the progress toward sustainability. According to the indicator rating and the results of the single SDG assessment, the degree of coordination of each SDG cluster was calculated through the mean ( $\mu$ ), standard deviation ( $\sigma$ ), and coefficient of variation (C.V.) (Figure 10). The C.V. is defined as the ratio of the standard deviation ( $\sigma$ ) to the mean ( $\mu$ ) [49]. It reflects the fluctuation of the goals evaluation in each field—the smaller the value, the smaller the fluctuation. The variation coefficient of three clusters were 0.091, 0.106, and 0.102, respectively. This indicates there is a good coordination among the three SDGs clusters (economy, environment, and society), with the economic cluster having the highest degree of stability and coordination. The higher coordination will help Deqing to aid the achievement of other SDGs.



Figure 10. Assessment result of three SDG clusters in Deqing.

### 4.4. Overall Assessment

Deqing County has made significant economic and social advances while maintaining a good ecological environment over the past few years. Good progress has been achieved in urban and rural development, balanced development, and green development.

One good example is the story of the Crested Ibis (Zhu Huan), one of endangered bird species in the world, which demands a high-standard living environment. Deqing was one of the native regions of the Crested Ibis (Figure 11). However, the wild Crested Ibis disappeared from Deqing in the late 1950s, due to the deterioration of the local ecological environment. For the past 15 years, 1720 rural domestic sewage treatment terminals have been established, covering 99.25% of administrative villages. In addition, 99% of the pig farm and polluting aquaculture have been shut down or terminated. In 2014, after the improvement of ecological environment and in situ conservation, 33 Crested Ibises returned to the wild state in the Xiazhu Lake. At present, the total population of Crested Ibis in the Xiazhu Lake has reached 323. The long-awaited Crested Ibis eventually has come home and settled in Deqing.



Figure 11. Home-back of Crested Ibis (Courtesy of the Government of Deqing County).

From the assessment data, it also noted that there is still room to improve. For example, the industrial emission should be further reduced, the energy consumption and material consumption should be lessened, the public transport convenience and other aspects need to be further improved, and the stability and coordination degree between the environmental sector and social sector are slightly inadequate.

## 5. Discussion: Lessons Learned and Experience Gained

It was found that the success of such a comprehensive SDGs measurement depends largely on a number of enabling conditions, such as the determination of local indicators and SDGs targets, availability of reliable geospatial information, moving to transformative actions, and the engagement of stakeholders and innovative partnerships [50].

### 5.1. Discussion: Lessons Learned and Experience Gained

Originally, SGIF was designed for tracking SDGs progress at national level. When applied to county (or local) level, a good number of the indicators may not be suitable. This makes it difficult to provide a full and rational coverage of all the primary SDGs of the study area. It is therefore imperative to conduct appropriate revision, extension, and even substitution. In the Deqing case, more than 53% indicators were determined through extension, revision, and substitution. This made the determination of the local indicators a particularly challenging task, and demanded an interactive collaboration among sustainability scientists, statistical staff, and geospatial information experts.

Another challenge is from the available benchmarks (references or criteria) used for the ranking of selected indicators. Currently, the SDGs dashboard and the National Plan mandate requirements

are the major references or criteria available. However, appropriate references or criteria could not be found for about 22% of the indicators in the Deqing case study. Besides, some references of the SDGs dashboard were found not suitable for developing countries and local scales. It is therefore necessary to explore and develop objective evaluation criteria for local SDGs studies.

Moreover, each SDG goal has many targets and makes it difficult to derive meaningful results of evaluation or assessment. A localization of SDG targets was implemented in the Deqing case by grouping the original SDGs targets into two to four local targets with clearly implied connotation. This facilitated the focused analysis of the achievement and existing problems for each of the 16 individual SDGs. The development and formalization of such a localized approach to SDG targets through connotation analysis needs to be taken into consideration in further investigations.

### 5.2. Availability of Reliable Geospatial Information

Geospatial information plays an irreplaceable role in measuring and monitoring the progress toward SDGs, such as disaggregating population census data in geographic space, providing geospatial parameters (accessibility, coverage, etc.), deriving SDGs indicators, and supporting the evidence-based qualitative analysis and location-based visualization. Without the utilization of geospatial information, a SDGs measurement and monitoring would not be 'comprehensive', as some indicators or targets can only be derived or analyzed from a geospatial lens. On the other side, this will demand more significant resources to prepare and make best use of geospatial information.

As far the Deqing case study is concerned, the county has been proactive to develop its geospatial infrastructure and related industries in the last 10 years. Multiscale and multitype geospatial databases have been put into place and a variety of value-added geospatial applications have been developed. This has facilitated the collection and preprocessing of the geospatial information in the Deqing pilot project, which was completed within a one-year period.

The availability and utilization of reliable and up-to-date geospatial information remains a big challenge for SDGs measurement and monitoring in large area. More automatic and operational techniques should be developed, such as the high-reliability computing of land cover and other core geospatial data, as well as the use of social media and other crown sourcing data.

## 5.3. Moving to Transformative Actions

With the results of this comprehensive measurement, an overall picture was created regarding how far Deqing County is from the 2030 SDGs. This helps local people gain a better understanding of where they stand and what the gaps are. A five-year action plan has been formulated by the local government to translate the 2030 Agenda into its own development vision and priorities, including a roadmap, implementation strategies, and monitoring mechanisms. Tangible actions have been planned with allocated resources to address the gaps and challenges, such as reducing industrial emissions, lessening energy consumption and material consumption, improving public transport convenience, etc.

Having identified the role of measurable indicators as a management tool, the county resolved to carry out regular monitoring and reporting of SDGs implementation performance. A dynamic monitoring mechanism is to be established. There are a number of items to be explored, including the design of key variables for regular monitoring, use of social media and other big data, problem diagnosis, and policy simulation.

#### 5.4. Engagement of Stakeholders and Innovative Partnership

The measurement and monitoring of the progress toward 2030 SDGs is a complex and open process that requires constructive engagement of scientific, users, policy, and other communities. First of all, researchers from seven research institutions and universities formed a multidisciplinary task force, covering sustainability, earth science, geography, remote sensing, and geoinformation, statistics, and computer sciences. This enabled the integration of knowledge from different disciplines in the process of indicator adoption, geospatial-enabled computation, and evidence-based assessment.

A strong multi-stakeholder engagement was received from more than 20 local governmental agencies, local communities, and other organizations of Deqing, such as the statistical office, planning department, etc. This injected considerable resources and support to the pilot study, including the identification of user requirements, provision of fundamental data sets, adoption of local indicators, and devising of local transformative actions.

Moreover, during the project preparation and execution, a group of high-level national and international experts was invited to provide constructive advice through over 20 meetings. Some of the experts come from the United Nations Statistics Division (UNSD), Ministry of Natural Resources of China, and National Bureau of Statistics of China. With the help of National Bureau of Statistics of China, several special meetings were convened to discuss the adoption of appropriate indicators and ranking of the results. A special session was organized jointly with UNSD during the first United Nations World Geospatial Congress to present and dissimilate the outputs of this pilot project.

### 6. Conclusions

This paper presents a story about the comprehensive measurement of SDGs in Deqing. In this study, 102 indicators were adopted and/or adapted for the assessment with the assistance of geospatial data. Analysis has been carried out at three levels, i.e., individual indicators, individual goals, and goals in three clusters. It was found that Deqing performs very well. With a total of 79 of the 102 indicators compared with benchmarks, 68 indicators reached or were very close to the objectives of the United Nations Agenda 2030, nine indicators needed improvement, and only 2 indicators faced challenges. At the SDG level, eight SDGs reached standards, six SDGs needed to be improved, and only two SDGs faced challenges. At the overall development level, the stability of the three clusters (economy, environment, and society) and the overall system of sustainable development were relatively high.

This paper shows that the overall SDGs progress at a local context can be well measured through developing a set of indicator-based, data-driven, and evidence-supported approaches with a geographic perspective and establishing a cooperative partnership among all stakeholders to mobilize resources. The geospatial information plays an irreplaceable role and assures a 'comprehensive' SDGs measurement and monitoring. A cooperative partnership among all stakeholders and research communities is another key element for success, which facilitates the integration of multidisciplinary expertise, mobilizing considerable resources and support. The measurement and assessment results provided an overall picture about how far Deqing County is from the 2030 SDGs, and enables the local government to formulate a five-year action plan to address the identified gaps and challenges with tangible actions and allocated resources.

The results of this project were presented and showcased at the first United Nations World Geospatial Information Congress, held from 19–21 November 2018 [37]. It was considered as a "Best practice for implementing and measuring SDGs at the local level" and received positive comments from the international community. The United Nations Expert Committee on Global Geoinformation Management (UN-GGIM) decided at the end of 2018 to "showcase the work as a flagship example on how countries can practically measure their progress using statistical and geospatial information, especially at the sub-national level". In 2019, it was selected by the United Nations as one of the "Best practices in SDGs implementation".

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