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PRECISION AND PARADIGM SHIFT: TRANSFORMING LAND AND BUILDING TAX ASSESSMENT THROUGH UAV-LIDAR DERIVED HIGH-RESOLUTION 3D SPATIAL DATA

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.ABSTRACT: The conventional Land and Building Tax (PBB) evaluation methods in Indonesia, namely in Baso District, Agam Regency, depend on two-dimensional measures with accuracy rates ranging from 85% to 95%, resulting in possible revenue deficits and assessment inconsistencies. This work seeks to create and execute a more precise tax assessment system utilizing high-resolution 3D spatial data obtained by UAV-LiDAR technology. The study utilizes a quantitative applied methodology, employing a DJI Matrice 350 RTK outfitted with LiDAR sensors for data acquisition. Data processing with DJI Terra and TerraSolid software produces Digital Terrain Models (DTM) and Digital Surface Models (DSM), facilitating accurate land boundary delineation and 3D building digitization. The findings indicate a substantial enhancement in spatial measuring accuracy, attaining 97-99% precision relative to traditional approaches. The implementation facilitates thorough property evaluation via precise measurements of building heights, volumes, and land areas, thereby offering a more dependable foundation for tax computations. The study suggests that, despite constraints including elevated initial costs and training demands, the inclusion of UAV-LiDAR technology significantly improves the accuracy, efficiency, and transparency of PBB assessments, representing a notable improvement in contemporary property tax administration systems.

Keywords: UAV-LiDAR Technology, Three-Dimensional Spatial Data, Land and Building Tax Evaluation, Property Tax Administration

1. INTRODUCTION

Taxation is a basic mechanism of contemporary governance, functioning as a vital tool for resource distribution, public service financing, and socio-economic advancement. Throughout human history, tax systems have progressed from rudimentary tribute collections to advanced fiscal frameworks that support national and local economic institutions. The fundamental aim of taxation transcends simple revenue collection, incorporating wider goals of social equality, economic redistribution, and sustainable community development [1].

In the realm of property taxation, land and building taxes represent a substantial element of local government revenue. These taxes furnish vital financial resources for municipal infrastructure, public services, education, healthcare, and community development projects [2]. The accuracy and equity of property tax assessments strongly influence governmental financial capabilities and the economic obligations of individual property owners. The Land and Building Tax (Pajak Bumi dan Bangunan or PBB) in Indonesia serves as a vital instrument for local government revenue creation. PBB was established by Government Regulation No. 20 of 1997 and has been improved via later legislative amendments to foster a transparent and equitable property taxation system [3]. The tax is determined by various elements, such as property location, land area, building attributes, and adjacent infrastructure, rendering precise spatial data collection essential for its effective execution [4].

Conventional property tax assessment methods have traditionally depended on manual surveying procedures, cadastral maps, and regular physical inspections. These methodologies necessarily face constraints, including protracted data acquisition, possible human error, and difficulties in collecting intricate geographical attributes [5]. The swiftly evolving urban and rural environments exacerbate these challenges, resulting in substantial discrepancies in precise property valuation and taxation [6]. Technological developments in geospatial sciences have emerged as transformational solutions to these enduring difficulties. The integration of Unmanned Aerial Vehicle (UAV) technology with Light Detection and Ranging (LiDAR) sensing constitutes a revolutionary method for spatial data collecting and processing . These technologies give unparalleled capacities to generate high-resolution, three-dimensional spatial datasets that capture precise aspects of land surfaces, architectural structures, and environmental attributes [7].

LiDAR technology, initially created for military and scientific research, has transformed into a potent instrument for diverse spatial mapping applications. LiDAR systems generate very accurate 3D point cloud representations of terrain and constructed settings by firing laser pulses and measuring their reflections [8]. When deployed aboard UAVs, these systems may acquire spatial data with centimeter-level precision, surpassing numerous constraints of conventional surveying techniques [9]. The geographical backdrop of Baso District in Agam Regency provides an optimal setting for investigating sophisticated tax assessment approaches. The district, marked by various topography such as mountainous regions and different land use, illustrates the intricate spatial issues that require novel technology solutions. Traditional mapping and valuation methods frequently fail to precisely represent the intricate spatial attributes of varied landscapes.

This project seeks to illustrate the capability of UAV-based LiDAR technology in transforming land and building tax assessment procedures. The project aims to overcome significant shortcomings in current taxing methods by utilizing high-resolution 3D spatial data, so providing a more accurate, efficient, and technologically sophisticated approach to property valuation. The main objectives are to formulate a detailed methodology for the extraction and analysis of high-resolution 3D spatial data, to evaluate the accuracy and efficiency of UAV LiDAR-based property assessment methods, and to examine the potential economic and administrative advantages for local government tax administration.

The importance of this research transcends mere technological demonstration. The study offers a comprehensive, data-driven methodology for land and building tax assessment, enhancing dialogues on technological innovation in governance, geographical data management, and the capacity of developing geospatial technologies to tackle intricate social issues.

2. METHODS

This study was performed in Baso District, Agam Regency, West Sumatra, noted for its varied geographical characteristics and adjacency to many neighboring districts. It employs a quantitative applied research methodology to improve Land and Building Tax (PBB) computations with 3D data derived from UAV and LiDAR technologies [10]. The procedures encompass recognizing problems in conventional methodologies, examining pertinent literature, and creating data gathering frameworks. UAV flights outfitted with LiDAR sensors and photogrammetric cameras gathered data, which was converted into 3D models (DSM and DTM) utilizing software like ArcGIS. The models were examined to assess building dimensions, volumes, and land areas, forming the foundation for computing the Taxable Object Value (NJOP) while accounting for market values and external variables. Validation was conducted by juxtaposing outcomes from the novel and conventional methodologies. The research utilized UAVs (DJI Matrice 350 RTK), LiDAR sensors, high-performance computing systems, and software such as DJI Terra and ArcGIS. This research seeks to enhance the precision and efficiency of PBB assessment methods, advocate for the integration of 3D technologies, and suggest methodological advancements. The results are anticipated to offer novel insights for property tax administration (Fig. 1).

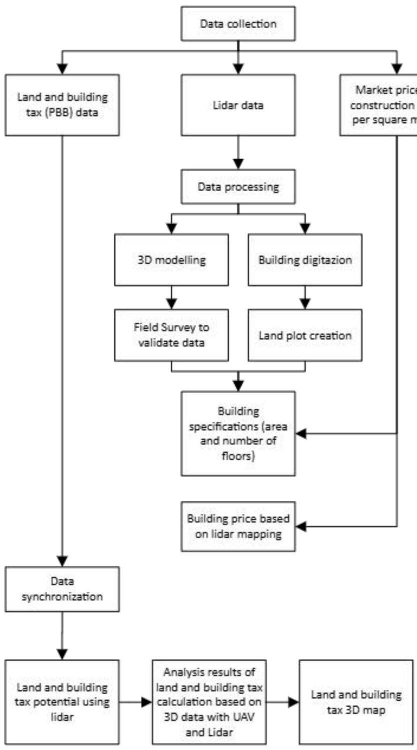

Fig.1 Research Workflow Diagram.

3. RESULTS AND DISCUSSION

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3.1 Results

The computation of Land and Building Tax (PBB) necessitates meticulous accuracy, especially in assessing the acreage and value of taxable assets. Technological breakthroughs have led to the utilization of Unmanned Aerial Vehicles (UAVs) fitted with LiDAR (Light Detection and Ranging) sensors as a contemporary method to improve the precision of tax assessments derived from 3D spatial data. This technology facilitates the identification of land and structures with enhanced accuracy relative to traditional 2D methods. The following are the methodical stages involved in the computation of PBB based on 3D data to ensure compliance with relevant tax legislation.

Development of Land Boundary Maps or Parcel Maps

The initial phase in the evaluation of Land and Building Tax (LBT) involves the development of land boundary maps or parcel maps (Fig.2). These maps are the fundamental basis for computing tax values, as they ascertain the exact extent and ownership of the land. Precision in delineating land borders is essential to prevent inaccuracies in establishing the taxable selling value of the property (Nilai Jual Objek Pajak-NJOP). Contemporary technology, including Unmanned Aerial Vehicles (UAVs) outfitted with Light Detection and Ranging (LiDAR) sensors, is utilized to guarantee accuracy in land border delineation. This technique facilitates expedited and precise mapping relative to traditional approaches, yielding more comprehensive and dependable spatial data [7].

The mapping procedure commences with the deployment of UAVs over the designated survey region. The LiDAR sensors on the UAVs emit laser beams towards the ground, recording the duration for the beams to return to the sensor. This technique facilitates high-resolution elevation computations, permitting precise mapping in regions characterized by dense vegetation or irregular topography. UAVs can traverse extensive areas rapidly, enhancing survey efficiency relative to manual approaches that necessitate greater time and labor [11].

After the collection of data from UAVs and LiDAR, it is processed with Geographic Information System (GIS) software. The raw data from the LiDAR sensors comprises a point cloud consisting of millions of three-dimensional coordinate points. The points are analyzed with spatial algorithms to generate Digital Terrain Models (DTM) and Digital Surface Models (DSM). From these processed datasets, land borders can be delineated and shown in digital map forms that facilitate interpretation by authorities.

Alongside digital data processing, the mapping outcomes must be corroborated using land ownership papers to ascertain data veracity. Documents such property ownership certificates, building usage rights, and land maps from the National property Agency (Badan Pertanahan Nasional or BPN) serve as references for verifying the delineated boundaries. Should conflicts occur between the mapping data and the current legal documents, additional modifications or elucidations are required. The verification process is crucial to prevent ownership disputes that may result in inaccuracies in tax computations and possible legal challenges.

The utilization of precise and validated parcel maps enhances the transparency and equity of the tax computation process. Potential boundary disputes are mitigated, enhancing public confidence in the taxing structure established by local governments. Moreover, the mapping data can be employed for many applications, including spatial planning, land resource management, and the analysis of temporal land use changes. The use of UAV and LiDAR technology in land boundary mapping signifies a progressive advancement in improving efficiency and precision in the administration of land and construction taxes.

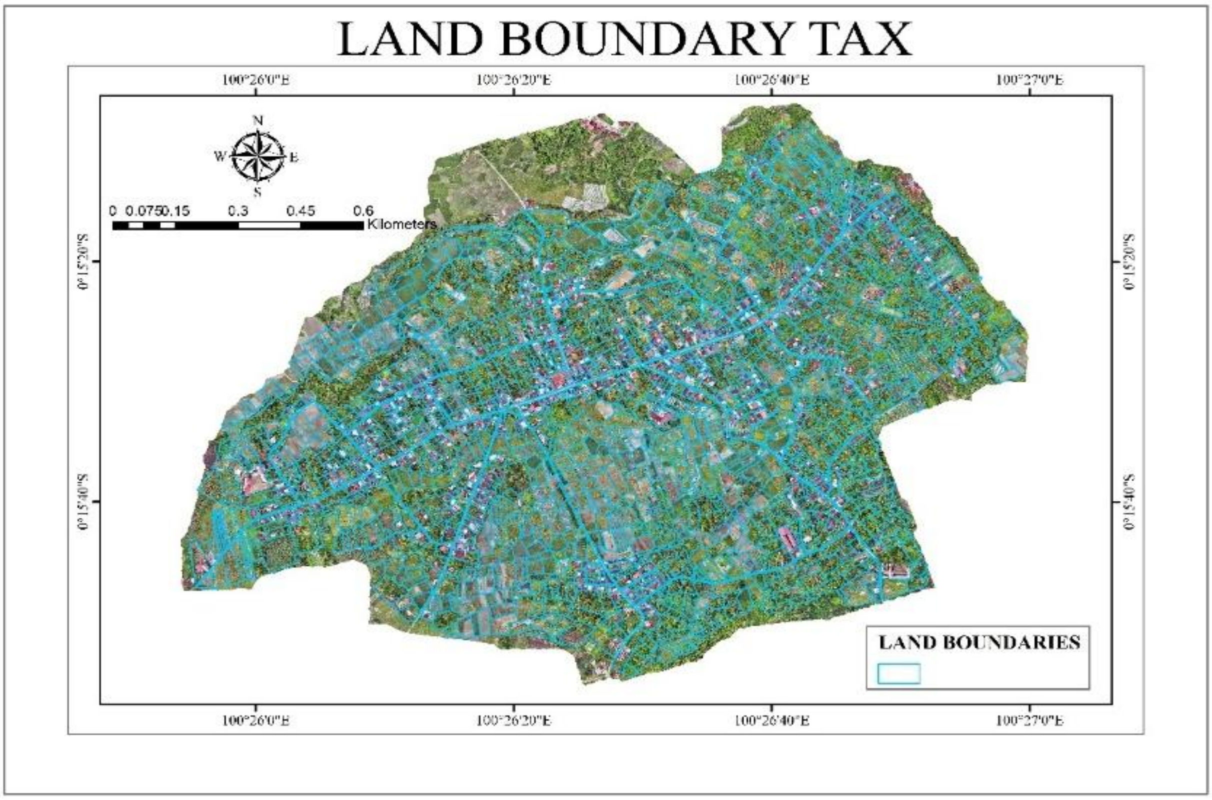

Fig.2 Land parcel delineation map.

Development of 3D Building Digitization

Following the delineation of land boundaries via precise mapping, the subsequent phase in the LBT evaluation process involves the digitization of three-dimensional (3D) structures. This entails redrawing and delineating the physical perimeters of each structure based on mapping data acquired from UAVs outfitted with LiDAR sensors (Fig.3). This approach enables more precise identification of structures compared to traditional 2D mapping techniques. 3D models enable a more realistic representation of every architectural aspect, encompassing floor spaces and building heights [12].

3D digitization ascertains both the land area occupied by a structure and its volume derived from vertical measurements. Traditional 2D approaches solely account for a building's footprint, neglecting the number of stories or overall height. Nonetheless, 3D methodologies precisely quantify each level of a structure, allowing for the NJOP to be determined based on the aggregate floor area rather than solely the building footprint. This leads to a more equitable taxation system, as multi-story buildings are assessed more precisely based on their economic value.

Furthermore, employing 3D models in building digitalization offers advantages for surveillance and spatial planning. Utilizing 3D building data, local governments can assess building density, urban development trends, and modifications in long-term spatial planning. This data is crucial in locating unregistered buildings within the taxation system, enhancing tax collection precision and broadening the local tax base. Thus, tax leakage may be mitigated, and local government revenue from LBT can be maximized.

Precise 3D building models enhance the transparency and accountability of the tax calculating process. Local governments can furnish taxpayers with more transparent information concerning the foundation of their LBT calculations, thereby diminishing the probability of tax disputes arising from data inconsistencies. Moreover, 3D models can mimic scenarios involving alterations in tax value resulting from building modifications, like renovations or the addition of floors. This technological innovation facilitates the seamless integration of the taxation system with GIS systems, allowing for extensive spatial surveillance. The application of 3D building digitalization improves the efficiency, accuracy, and equity of Land and Building Tax assessment.

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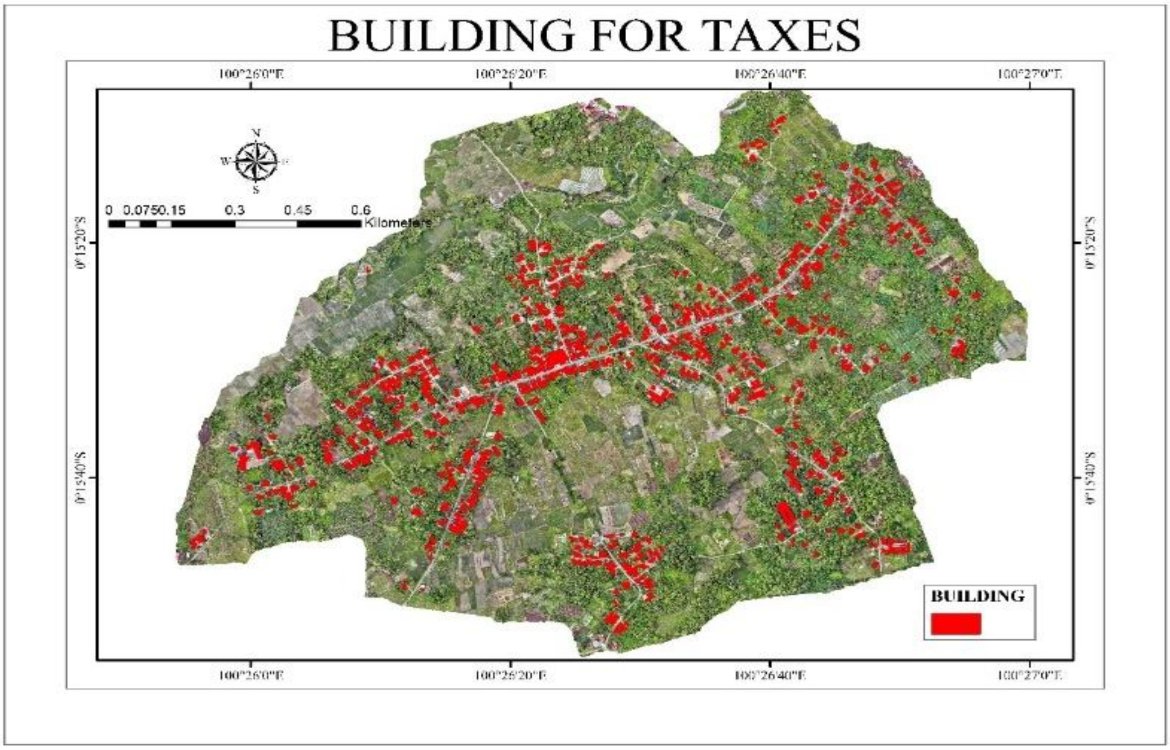

Fig.3 Development of a 3D Building Digitization Map.

Assessment of Taxable Sale Value of Property (NJOP)

The subsequent phase involves ascertaining the Taxable Sale Value of Property (NJOP), which constitutes the principal foundation for computing LBT. NJOP is determined by multiplying the digitized land and building areas by the prevailing market value in the region. This value is established by local authorities by regular assessments of land and building market prices .

Two primary components are evaluated in the determination of NJOP:

a. NJOP of land is determined by multiplying the land area in square meters by the price per square meter established by the local government.
b. NJOP of Buildings: Determined by multiplying the building area in square meters by the price per square meter, which is contingent upon the building's material specifications and structural design.

Calculation of Land and Building Tax (LBT)

The LBT tariff is set at 0.2%, as mandated by Agam Regency Regional Regulation No. 1 of 2024. Non-Taxable NJOP (NJOPTKP): IDR 10,000,000 (as established by Agam Regency Regional Regulation No. 1 of 2024).

a. If NJOP surpasses IDR 1,000,000,000, the NJKP (Taxable Sale Value) proportion is 40%.

b. If NJOP is less than IDR 1,000,000,000, the NJKP proportion is 20%.

Procedure for Computing LBT:

a. Ascertain NJOP: NJOP represents the market value of the land and structure. Local governments often establish this every three years.
b. Determine NJKP: NJKP constitutes 40% of NJOP when the NJOP value beyond IDR 1,000,000,000, or 20% when it is below IDR 1,000,000,000. Furthermore, the Non-Taxable NJOP (NJOPTKP) must be deducted, currently established at IDR 10,000,000.
c. Compute LBT: Following the acquisition of NJKP, LBT can be determined as outlined below:

The formula for computing Land and Building Tax (LBT) complies with the stipulations set forth in the Ministry of Finance Regulation No. 186/PMK.03/2019 on Property Tax Object Classification and Taxable Sale Value Determination Procedures. This law delineates the procedure for ascertaining the NJOP, which underpins

LBT calculations, along with the NJKP percentages of 40% for NJOP values beyond IDR 1,000,000,000 and 20% for values below IDR 1,000,000,000. This framework guarantees that LBT calculations are performed accurately, transparently, and in accordance with the requirements set forth by the Ministry of Finance.

These data can be utilized for many applications including spatial planning, environmental assessment, and engineering. A methodical approach and suitable parameter configurations guarantee that the data processing outcomes conform to the necessary geographical standards. The utilization of UAVs equipped with LiDAR sensors facilitates precise and expedient mapping of terrestrial surfaces and architectural edifices. Unmanned Aerial Vehicles can traverse extensive regions and acquire high-resolution geographical data. LiDAR sensors affixed to UAVs operate by emitting lasers onto the terrestrial surface and recording the reflected signals to generate a spatial point cloud. The data is subsequently transformed into a 3D model that illustrates the land's terrain along with the building's shape and proportions.

The preliminary phase of this research commenced with the planning of the UAV flight mission in Baso Sub-district. The survey region encompasses residential zones, undeveloped terrain, and business districts. The gathered data was further analyzed with DJI Terra and TerraSolid software, capable of processing point clouds, classifying land and building components, and generating digital elevation models (DEMs) and vectorized building models. The 3D model produced from LiDAR data processing serves as the foundation for assessing the value of the tax object. Within the framework of PBB, the spatial data derived from the 3D model encompasses land area, building area, building height, and total building volume. All these elements are amalgamated with administrative data, including zoning, tax object sales value (NJOP), and building function, to compute the final value of PBB. A building with a substantial area situated in a commercial zone will possess a greater PBB value compared to a building placed in a residential zone.

This method facilitates the identification of physical alterations to land and structures that transpire throughout time. Modifications, such as the incorporation of an additional building level or area expansion, can be automatically detected by comparing point cloud data with prior surveys. Consequently, 3D data establishes a robust foundation for the frequent updating of tax object information, which has historically been a significant impediment in PBB management.

This study effectively generated a UAV and LiDAR-based three-dimensional model for the Baso District region. The model incorporates thoroughly tested land and building data, enabling more precise calculations of PBB compared to manual data. The data acquired from UAV and LiDAR demonstrate significant potential in enhancing the transparency and precision of PBB evaluation. Enhanced mapping enables local governments to augment the tax object database and mitigate any revenue loss stemming from inaccurate or obsolete data. The application of three-dimensional (3D) data in land and building tax assessment represents a substantial advancement over conventional two-dimensional (2D) techniques. Contemporary mapping technology employing UAVs equipped with LiDAR sensors may produce digital models with significantly greater resolution and precision than traditional techniques. The essential distinction resides in 3D technology's capacity to encapsulate the genuine intricacy of a property, a feat unattainable by planar measurements on a 2D map.

The primary benefit of the 3D technique is its measurement precision. This technology can accurately estimate the volume, height, and slope of buildings, surpassing manual approaches in precision. The local tax office (Bapenda) utilizes Google Earth, leading to diminished measurement precision relative to UAV LiDAR. Google Earth offers data in a two-dimensional format with an error margin of 5% to 15%, whereas UAV LiDAR generates three-dimensional data with a markedly reduced error margin of about 1% to 3%. Consequently, UAV LiDAR is significantly more efficient for land and building tax evaluations, as it yields more precise and comprehensive data that correspond with actual field circumstances. All architectural details, including uneven roof structures, terracing, and buildings with intricate shapes, can be thoroughly identified. This differs from 2D approaches, which provide only flat projections and are constrained in accurately representing the true attributes of a property.

UAV LiDAR delivers data that accurately reflects actual conditions, hence minimizing the likelihood of errors in computing NJOP (Nilai Jual Objek Pajak or Property Sales Value). The 2D technique exhibits a greater error margin (5–15%) owing to its constraints in precisely representing vertical dimensions and architectural forms. These inaccuracies may escalate in highly populated, hilly, or vegetated regions. UAV LiDAR, with a little 1–3% error margin, produces exceptionally accurate 3D data, eliminates perspective distortion, and enables precise measurement of building heights and volumes.

Temporal and financial efficiency are significant benefits. Field surveys that formerly required weeks can now be accomplished in few days. A solitary UAV flight mission can produce extensive data for a large area, considerably diminishing the want for on-site surveyors and lowering operational expenses. This method has shown significant promise in enhancing property data collection processes for tax assessment in Baso District (Fig. 4).

somewhat substantial, and skilled staff are necessary to operate and evaluate the data. Nevertheless, sustained efficiency and enhanced precision can rapidly counterbalance these initial expenditures. Local governments may adopt the technology incrementally, prioritizing commercial districts or regions with significant tax potential.

The integration of 3D technology with geographic information systems (GIS) and local tax databases represents a potential strategic advancement. This will provide a cohesive digital ecosystem that is interconnected, adaptive, and

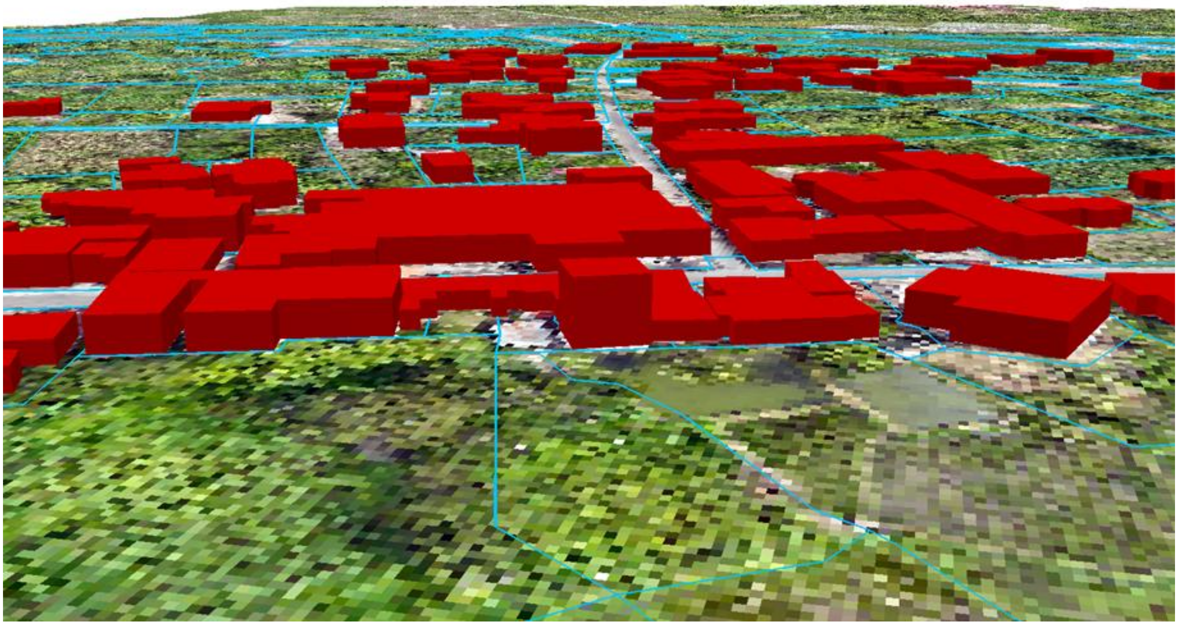

Fig. 4 Policy Model of Adaptation Mitigation and Social Risk of The Volcano Eruption of Sinabung.

The clarity of the taxation system has markedly enhanced due to the implementation of 3D technology. Digital visualization facilitates a mutual comprehension of assessed properties between local governments and taxpayers. All architectural details are accessible and verifiable, significantly diminishing the likelihood of conflicts or misunderstandings in tax assessments. The 3D model serves not only as a measurement tool but also as a potent communication device between the government and the people.

A significant benefit of 3D technology is its capacity to identify unlawful or unregistered structures. This technique can detect structural alterations, building expansions, or land use discrepancies that are inconsistent with official records through thorough geographical analysis. This offers a substantial opportunity for local governments to guarantee compliance and enhance potential tax collections that may have been previously neglected. Undoubtedly, the adoption of 3D technology presents certain problems. The initial expenditure for hardware and software is

proficient in providing more precise and sustainable tax services. Research in Baso District has shown that digital transformation in tax assessment is essential for the future of contemporary governance. The investigation categorizes the efficacy scores of UAVs and LiDAR in 3D-based Land and Building Tax (PBB) assessments. If this technology achieves a score exceeding 80% in all categories, UAVs and LiDAR can be deemed highly effective for 3D-based PBB evaluations. Nevertheless, if the score lies between 60% and 79%, the technology remains successful but need modifications, especially regarding cost and system integration. If the score is below 40%, the deployment of UAVs and LiDAR for PBB objectives encounters numerous problems. UAV LiDAR, with an accuracy level of 1–3% and time efficiency surpassing 80%, has proven to be superior to manual or 2D-based approaches in the 3D-based PBB assessment process.

The integration of UAV and LiDAR technology in Baso District offers numerous

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concrete advantages in PBB management. A primary advantage is the efficiency in time and cost associated with geographic data collection. Prior to this technology, mapping operations frequently included laborious field surveys that could take weeks or even months. The entire Baso region may be mapped within a few days using UAVs, resulting in more detailed and precise outcomes.

3.2 Discussion

The utilization of UAV and LiDAR technology for the computation of Land and Building Tax (PBB) utilizing 3D data in Baso District, Agam Regency, in 2024 signifies a significant advancement in the efficiency and precision of regional tax administration. This technology supplants traditional 2D data-centric methods that frequently lack precision in depicting taxable entities, such as real estate and structures. UAVs outfitted with LiDAR sensors may acquire detailed spatial data in the form of three-dimensional models, including metrics on height, area, and volume of objects. These models not only offer a more authentic visual depiction but also facilitate a more profound investigation of the taxable object sale value (NJOP), which underpins the PBB calculation. Geospatial mapping theory posits that 3D models are superior in depicting the intricacies of field objects, including terrain variations and building size, in contrast to 2D models, which primarily convey horizontal data.

The principal benefit of employing 3D data in tax assessment is markedly enhanced precision. The 2D technique sometimes overlooks vertical components, inadequately representing building measurements, particularly for multi-story edifices or those with intricate designs. This corresponds with the tenets of geoinformation, highlighting the significance of spatial detail for data-informed decision-making. In Baso District, LiDAR technology may detect variations in elevation, building extensions, and previously unreported things in the tax database. This benefit immediately influences the augmentation of regional revenue, as PBB calculations can be executed more equitably and openly, grounded in actual field conditions. This technology accelerates survey and mapping procedures, save time formerly needed for manual surveys.

It is essential to recognize that mapping outcomes derived from UAVs and LiDAR can only function as initial estimates in the assessment of Land and Building Tax (PBB). The produced data illustrate spatial representations of object heights and dimensions, although they do not consistently correspond to the real values or overall physical state of buildings. Consequently, UAV data cannot serve as the exclusive foundation for PBB calculation. Field verification is required to confirm the compliance of taxable objects with the acquired spatial data. This underscores that UAV technology serves solely as an ancillary instrument in the evaluation process, rather than a comprehensive substitute for traditional approaches.

Notwithstanding its benefits in precision and efficacy, UAV technology possesses many limits. A limitation is that the generated data exclusively offers top-down perspectives, which frequently do not accurately depict the actual state of houses, including the extent of structural damage, materials utilized, or alterations in the inside. This contrasts with direct field study, which facilitates comprehensive observations of the physical state of structures. This constraint may lead to an absence of essential supporting information required for PBB evaluations that accurately represent the actual state of taxable entities. Consequently, field surveys are essential as a verification measure to augment UAV-based mapping outcomes.

This study encounters problems that require resolution. A primary difficulty is the substantial upfront expenditure associated with acquiring UAV devices, LiDAR sensors, and data processing software like DJI Terra and TerraSolid. Moreover, the implementation of this technology necessitates expertise in UAV operation as well as point cloud data processing and analysis. This requires local governments to invest in human resource training. A further constraint is the susceptibility to noise in point cloud data, including inaccuracies in object classification or absent data in regions with extensive vegetation. The data processing phase necessitates accurate parameter configurations, including the classification of ground points and above-ground entities, to guarantee dependable final outcomes.

The utilization of LiDAR technology in Baso District offers strategic advantages beyond PBB management. The resulting 3D data can be employed for spatial planning, disaster mitigation, and natural resource management. This technique enhances data-driven decision-making in sustainable development theory, facilitating the identification of landslide-prone regions and the planning of topography-based infrastructure. To ensure sustainability, the integration of 3D data with existing Geographic Information Systems (GIS) and periodic data upgrades is necessary.

The utilization of UAV and LiDAR technology in Baso District has profoundly influenced PBB management through 3D data. This technology enhances regional revenue potential and fosters transparent governance through its high accuracy and time efficiency. Notwithstanding the hurdles associated with cost and operational complexity, the long-term advantages, both technical and socio-economic, render this technology a worthwhile investment. This study corroborates the hypothesis that contemporary geospatial technologies, like as LiDAR, can revolutionize regional and tax administration, yet necessitate ongoing policy and training support to optimize their advantages.

4. CONCLUSION

The incorporation of UAV-LiDAR technology in Land and Building Tax assessment for Baso District has shown considerable promise for transforming property tax administration. The high-resolution 3D data collecting system offers unparalleled precision in quantifying building measurements and land areas, with error rates of 1-3% in contrast to the 5-15% typical of conventional methods. The technology's capacity to acquire intricate geographical data, encompassing building heights, volumes, and topographical characteristics, facilitates more accurate and equitable tax assessments. Notwithstanding the constraints posed by initial implementation expenses and the necessity for technical skills, the system's efficacy in encompassing extensive areas and producing detailed property data provides significant long-term advantages for local government income generation. The research validates that 3D assessment utilizing UAV-LiDAR technology is a substantial improvement in property tax administration, however it necessitates field verification for full efficacy. This study lays the groundwork for the future application of contemporary geospatial technology in tax assessment systems, advocating for a gradual adoption strategy that prioritizes high-value regions while ensuring compatibility with existing geographic information systems.

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