Sustainable Housing Practices: Spatial Analysis of Housing Stress in Corvallis, Oregon

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Abstract: America's Housing Affordability definition classifies those households as stressed that spend more than 30% of their net income on housing. This paper challenges the traditional economic criteria-based approach that ignores the social and environmental parameters. Authors offer a geographical information science (GIS)-based Multicriteria Decision Analysis, selecting Corvallis, Oregon to prove the applied impact of the proposed methodology. Using experiential literature and interviews with specialists, the research establishes a comprehensive set of housing stress indicators including demographic, housing quality, and commuting time variables. Raster overlay and zonal statistics were deployed to obtain the final housing stress map. The strain was highest in the low-density single-family zone that contained dilapidated housing and longer commuting times, in contrast the stress was lowest for the mixed-use residential. GIS results were then used to make recommendations for affordable housing by channelizing favorable allocation of resources through spatially targeted efforts. This innovative method has a great potential to prioritize improvements based on the accumulated stress scores for each zone and contributes toward the improvements in understanding, examining, and measuring housing stress worldwide. **DOI: 10.1061/(ASCE)UP.1943-5444.0000629**.

Author keywords: GIS; Raster analysis; Housing affordability; Housing Stress and Multicriteria Decision Analysis.

Introduction

Housing affordability and stress is considered as an emerging land use planning and public policy issue for the past few years. Sustainable housing governance targeting the human rights to adequate shelter, including the safety, comfort, convenience, and amenities for citizens, is the need of the day. With world population budding at such an unprecedented growth rate, the need for adequate housing is becoming increasingly vital. Accordingly, the role of spatial analysis as a tool to assist the decision takers formulating national and regional housing policies is also being recognized. The new decision support system prescribed through this research will help government make informed decisions and fairly target the regions in need of adequate housing and will also support the allocation of funds for housing in an efficient manner.

Wheeler defines "*Sustainable housing as a state in which all residents in a given area can satisfy their needs for diverse, healthy, affordable, socially-inclusive, resource-efficient, and culturally sensitive homes*" (Wheeler 2013). Therefore, sustainable practices try to ensure adequate housing through rightful supply of land, housing, and amenities at affordable costs to all segments of the society. In other words, it is the provision of good-quality housing at an affordable price keeping in view the social, economic, and environmental aspects in terms of both short- and long-term sustainability (Singh 2012).

The conventional approaches in the United States use "housing affordability" as a solitary measure to quantify housing sustainability. All the households who pay more than 30% of their total earnings for housing (counting expenses and interest or rent, services, and insurance) are categorized as cost burdened and may be struggling to pay for other living expenses such as food, medical, and childcare. Accordingly, around 50% of the US population falls under this domain (Jewkes and Delgadillo 2010). The Joint Center for Housing Studies (JCHS) at Harvard has also been using the same matrices for 30 years to measure and gauge housing-cost burden throughout the nation (Herbert et al. 2018). Overall, in terms of affordability it is believed that when the total spent on housing outstrips the 30% threshold, households are prone to experience housing stress (Liu et al. 2016). Furthermore, this approach does not account for accumulated capital as well. The gap between the household earnings and expenditure is decreasing, thus making housing affordability a critical issue. As such, defining and measuring housing stress and affordability forms a big challenge for policy makers (Belsky et al. 2005).

It is asserted unanimously that housing affordability is a well-recognized subject for the masses but cannot be claimed as the only rationale contributing toward housing stress (Pelletiere 2008; Desmond and Gershenson 2016). Although this metric is broadly accepted in the real estate industry, it is overly simplistic to conclude that spending more than 30% of household earnings on shelter is inherently unaffordable (Boyack 2018). Alternatively, the recent researches present a set of three categories of indicators that together help identify the pressure on housing (Bacon et al. 2012; Rowley and Ong 2012). These include:

- Housing availability—indicators include price to income ratio, homeless count, affordable housing index, house ownership rate, average annual vacancy jobs/housing ratio.
- Housing condition—indicators such as age of dwellings, condition of dwellings, percentage of houses in need of major repair.

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- Housing costs—indicators include the cost of housing, average property tax as a percentage of median family income, home ownership rate, rent to income ratio, and commuting distance/time to work (in case the worker is hit by a jobs/housing mismatch).

Keeping in view the critical issue of housing affordability, this research presents stress mapping through advanced spatial analysis of raster overlay to measure the overall housing tensions in a given area. The anticipated technique can identify the existing conditions of housing stress using socioeconomic and environmental parameters, which have been ignored in the underuse of the existing indicators. This assists in the graphical representation of the data analyzed, which provides a benchmark for future residential development. It also helps to gauge the efficiency of the zoning code and is believed to reap fruitful results in addressing loopholes in housing policies not just in the United States but worldwide. Moreover, the global applications of this prescribed method will help urban planners combine and assess a range of factors contributing to housing stress, which will help them make data-driven choices to prioritize future improvements in the residential zones through resourceful management of housing finance.

Methodology

Recognizing the importance and scope of the suggested tool, this paper identifies the desirability to apply it on a selected area to quantify the housing stress. This demonstration is executed through the selection of Corvallis, Oregon as the study area. The chief reason behind this choice is the tight housing market of the city, which will be discussed in detail in the forthcoming sections. The modus operandi proceeds with the development of a conceptual framework for quantifying the pressure in existing residential zones and empirically mapping the stress indicators. Hence the objectives of this research include analysis of the current housing stress situation in the case study area, evaluation of the stress results to formulate policy guidelines geared to overcome the current housing burden, and finally the recommendations for the replicability of the proposed methodology to other areas worldwide. The succeeding section presents a synopsis of the literature related to the tools of measuring housing affordability and stress. The discussion includes interviews with local planners, housing consultants, and developers working in urban regeneration through public–private partnerships. Next the study area is introduced and followed by the "Analysis section," employed to calculate and map the selected indicators using an all-inclusive set of criteria. The last section offers the results and discusses a way forward, identifying suggestions and constraints of the current research at the end. Policy interventions to match the market demand are also presented as future housing improvement strategies.

Literature Review

Existing literature offers a diverse range of definitions for observing and scrutinizing housing stress. Conventionally, housing stress was described as a condition wherever the cost of housing (both as rental and as mortgage) is high relative to household income. The efforts have been solely targeted to estimate housing affordability using the following measures (Stone 2006):

- Cost to income ratio (CIR)
- Supply demand mismatch (variation of CIR)
- Fair-market rent (used in relation to CIR)
- Housing wage (given by national low-income housing coalition)
- Housing affordability index (HAI)

Although understanding housing affordability issues is intricate and involves subjective judgments, it cannot be treated as the solitary measure contributing toward housing sustainability. Scholarly works are full of assertions that these relevant benchmarks turn a deaf ear to the tradeoffs people make to reduce pressure on housing; for example, moving to affordable neighborhoods by incurring extra costs on transportation, safety, and the associated fatigue (Mason et al. 2013). Neither does it account for the accumulated wealth that, for example, a retired couple may have when compared with university students or a young pair. Hence, the conventional definition of housing affordability is not all-inclusive, making the determination of whosoever qualifies in this crisis multifaceted. Typical measures used by the affordability advocates do not successfully allow for the compromises that households make to lower housing costs (Belsky et al. 2005). In other words, simple definitions and mapping of housing affordability crisis following the basic economic principles of demand and supply allow for meek calculations based on readily available data. These can easily be comprehendible to a layperson yet they do not include the adjustments such as transportation costs, location compromises, and household size (JCHS 2012; Liu et al. 2016).

Housing crises in the United States is quite evident with the homeownership rate dropping to 64.4% by the second quarter of 2018 (US Census Bureau) (Fig. 1). The US housing is hitting hard equally on home buyers and renters with an increase of house prices by 5.6% in 2016 (JCHS 2012), declaring that the prices have been at a record high after a ten-year span of great recession. Current data underlines the explanations for being concerned. As shown in Fig. 2, the 2015 American Housing Survey Data plotted by the US Department of Housing and Urban Development depicts an alarming figure of 8.30 million renters under worst case housing needs. A typical "worst-case needs household" can be defined as a renter with worst case housing needs; for example, a family with two children, most often a minority family headed by either a single female or a married couple. The family resides in adequate or good-quality housing in a central city of a southern metropolitan area. Wages are the family's primary source of income, yet their low wages place them below the poverty line and in the extremely low-income category. Their rent plus utilities consume most, if not all, of their extremely low reported income, costing more than $1,000 per month on an average for the country. The report documents severe rent burden coupled with insufficient tenant incomes (paying more than one-half of income for gross rent) and scarce supply of adequate housing as the chief reasons underlying this trend (Watson et al. 2017). This stressed housing market calls for innovative methods to measure housing affordability and sustainability. The policy makers and city planners need to identify reliable, efficient, and effective decision support systems to assist them in measuring housing stress in order to formulate a sustainable housing response.

There is a dire need to devise a methodology that could help the decision takers to identify and target the complex issue of housing affordability and stress. Some researchers have provided alternate concepts of residual income to counter the 30:40 housing affordability rule, whereby the residual income is established by subtracting the household spending (depending on the size and composition of the household) from the gross income by declaring the outstanding amount as "leftover income" available for housing (Herbert et al. 2018). Other studies have made attempts to improve the indicators for measuring housing stress involving multicriteria assessment models to evaluate housing crises. These involve the weighing and accumulation of certain socioeconomic, housing, and environmental quality metrics (Nuuter et al. 2015; Chiu 2004).

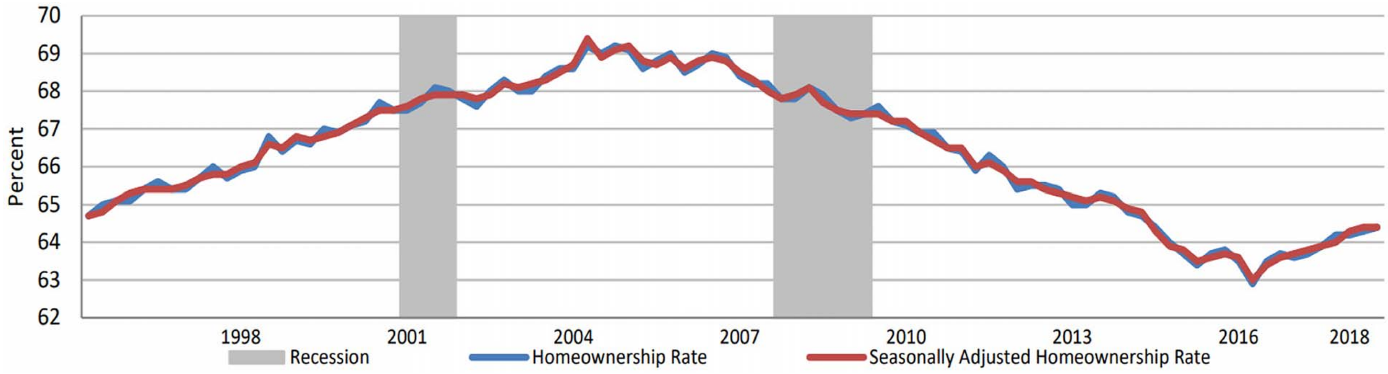

Fig. 1. (Color) Quarterly home ownership rates and seasonally adjusted homeownership rates. (Data from U.S. Census Bureau 2018a.)

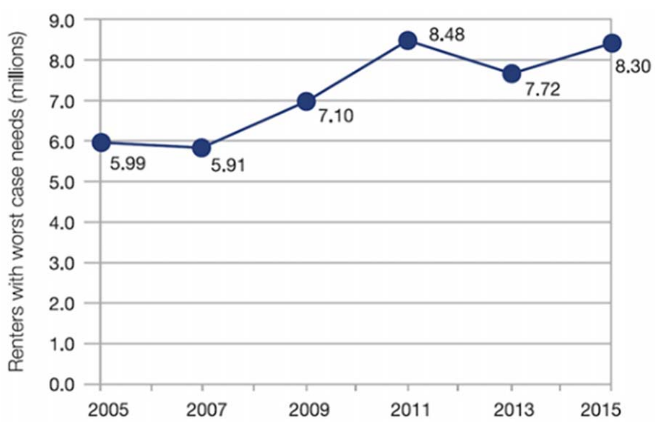

Fig. 2. Growth in worst case housing needs (2005–2015). (Reprinted from Watson et al. 2017.)

Traditionally, a "Housing Stress Map" has been used as a tool to create a series of housing area characteristic maps for a selected region. Combining these individual paper maps through overlapping constitutes the "Final Stress Map." With the advent of technology, spatial analysis through geographical information science (GIS) has revolutionized these orthodox practices making them an imperative instrument for the measurement of urban residential area characteristics (Geoghegan et al. 1997; Can 1998; Thomson and Hardin 2000; Al-Shalabi et al. 2006; Perkins et al. 2009; Liu et al. 2016; Zhang et al. 2015). Utilizing the power of this technique, a range of variables was selected to cover the social and environmental aspects of housing for the selected region. To initiate the application of the aforementioned technique, the next section briefly introduces the selected case study area.

Case Study Area

University towns have a high demand for renter-occupied housing due to the large population of students. The exploration of their residential structure and dynamics is unique yet interesting. The impacts of livability, outstanding public services, cultural offerings, and social diversity make them popular among the masses. Corvallis, Oregon is not an exception, ranking fifth among the list of the best college towns in America (Livability 2018), the city rests in the lap of the beautiful Willamette valley with intriguing scenic vistas from the Cascade Range. Geographically, as Fig. 3 illustrates, it is located about 85 miles (137 km) south of Portland with close proximity to the nearby towns of Lebanon, Albany, Philomath, and Salem. It has a total area of 14.43 mi^2 (37.37 km^2) with a population of around 59,000 (2017). Out of which 35% of the population are college/university students (Portland Research Centre). Bicycle lanes, parks, and trails improve the overall quality of life in Corvallis. Oregon State University, HP research campus, Good Samaritan Regional Medical Centers, CH2M Hill Companies, AVI Bio-Pharma, and other high-tech industries style the city into an educated community.

A report by EcoNorthwest predicts that the population of the city will increase to 69,527 people by 2036, resulting in the need for an additional 177 dwelling units per year. Yet, the median household income of the city is a mere $39,493, which is much less than the state's median of $49,510 annually. Moreover, Corvallis has a very high share of college/university-going young adults aged 18–24, that is, 32% compared to the state average of 9%, the majority of them attending Oregon State University and Linn-Benton Community College. Fig. 4 shows that this population segment has a very low income, with 78% of them earning below $25,000 annually (EcoNorthWest 2016). They are dependent on the fiscal support from parents, college loans, and other lending agencies. Even if a section of them have some affordability, their low creditworthiness would not allow them to clear the housing mortgage approvals.

Housing Market

The housing market of Corvallis is extremely complex and yet diverse when compared with the other cities of Willamette Valley. It is a rich rental market having low options for affordable housing. The city has a greater share of renter-occupied housing, which is much more than its counterpart Eugene home of "University of Oregon," whereby 56.3% is "renter occupied" (2014 statistics) with the student population forming a major share of this percentage (Parker and Goodman 2014). Moreover, a hefty proportion of 63.1% workers of Corvallis live elsewhere and have to commute to the city for work (source: inflow/outflow analysis by authors). The analysis further indicates a job count of 10,030 workers going out of the city and 15,536 workers coming into the city on a daily basis for work, with as little as 9,090 workers both living and working within the city's jurisdiction. This indicates an extremely disturbed job/housing ratio demonstrating a total mismatch of the income groups working in the city to the available housing, justifying the dire need to investigate housing stress based on commuting times for the area. The results depict a notable estimate of 40% of the total workers in the city, commuting more than 16 km (10 miles) daily as a part of their work trip and round 30% travelling even more than 40 km (25 miles) per day, this places a lot of pressure on the existing transportation infrastructure

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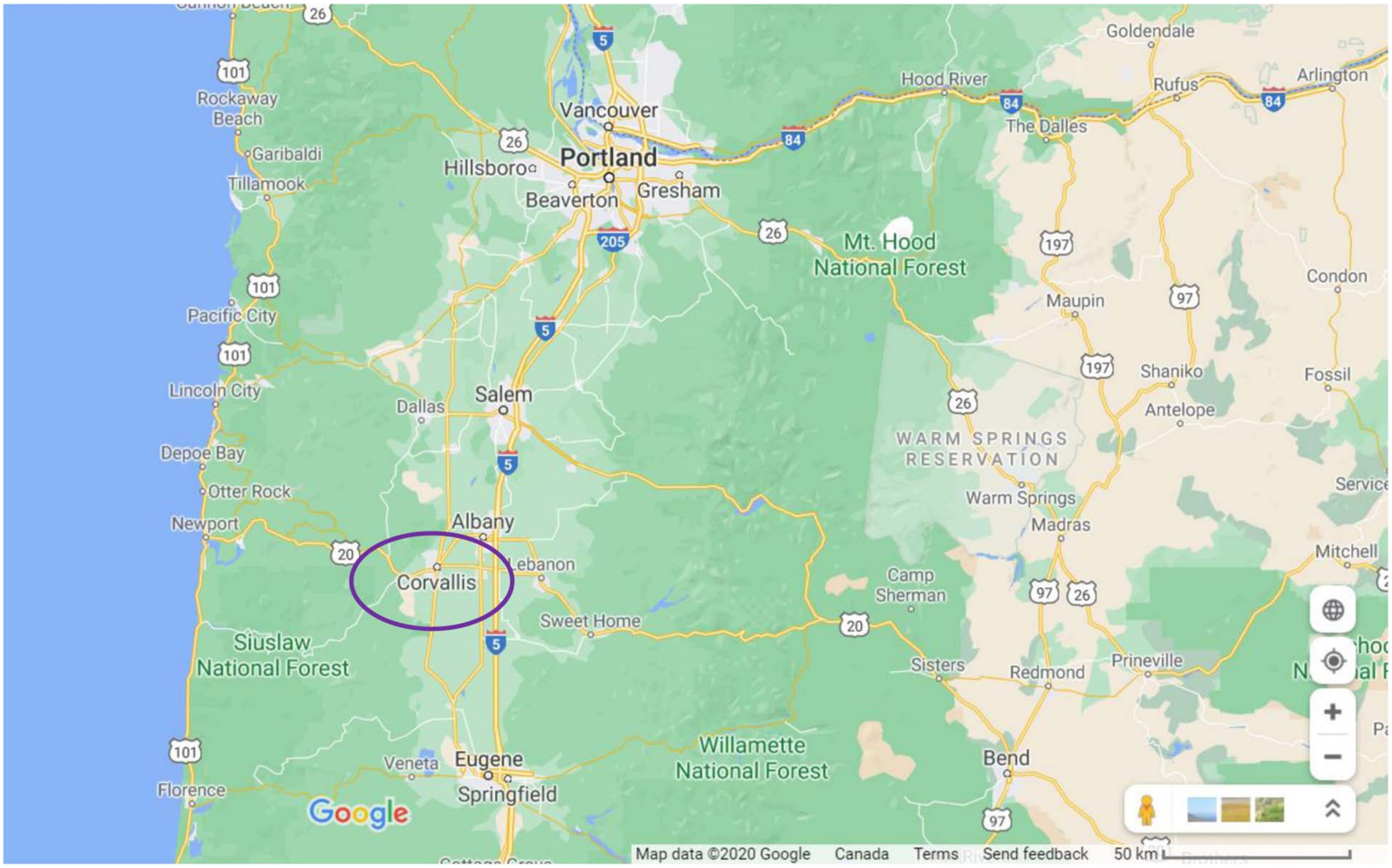

Fig. 3. (Color) Location map Corvallis. (Map data ©2020 Google.)

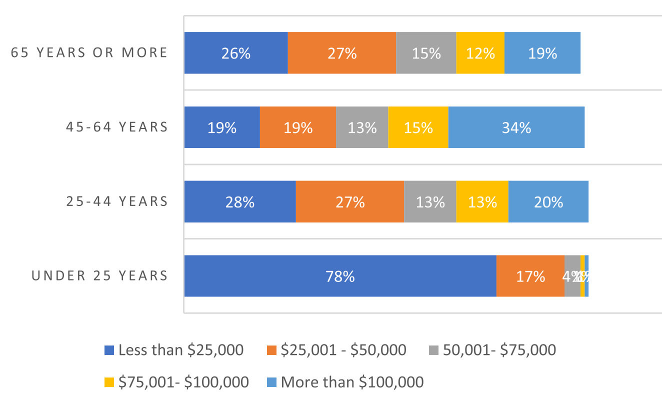

Fig. 4. (Color) Household income by age of householder, Corvallis. (Data from ACS 2011–2013.)

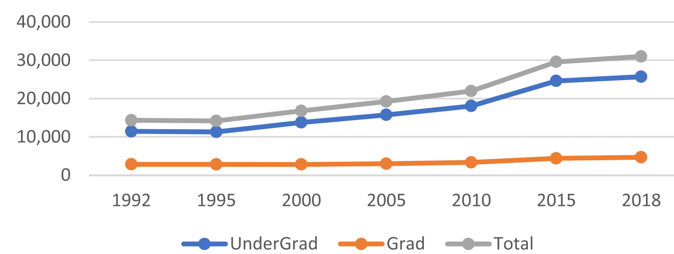

Fig. 5. (Color) Oregon State University enrollment fall 1992–fall 2018. (Data from Office of Institutional Research 2018.)

apart from the mental fatigue experienced by these commuters (source: distance/direction analysis conducted by the authors using On the Map Online by US Census Bureau, Center of Economics Jan 2018).

The price of the current housing stock is remarkably high while the quality of available housing is predominantly low. In particular, the aged stock near or around the downtown seems to be uninviting to higher income groups possibly due to its inferior quality, forming the greater part of the rental market occupied by university students (Odegard 2018). The average median sales prices for single-family houses are also much higher than neighboring cities such as Albany and Philomath (Parker and Goodman 2014). The city is experiencing high demand and low inventory with a mere 62 approvals of single-family residence permits in 2017. Consequently, the demand and supply gap is widening in the housing market, making it unreachable for the middle and low income. Corvallis experienced an escalation of 8% in the average home price, increasing its mean from $374,000 (2017) to $384,000 (2018) for a single-family unit for the same year (Odegard 2018).

Reportedly, several college students in the city have issues finding reasonably priced housing opportunities near their campus (US Department of Housing and Urban Development 2017). This stressed housing market in Corvallis has been attributed to the exceptional increase in the Oregon State University enrollment, slow pace of addition of new housing stock due to local resistance through vote of annexation, ambiguous land use code/policies, and increased developer costs. The existing residential offerings in the city are becoming progressively squeezed with Fig. 5 showing the student enrollment at OSU increasing from around 14,000 in 1992 to 31,904 by the end of 2018 (Office of Institutional Research 2018). According to the "Housing Affordability Analysis"

Table 1. Summary of vacant residential land in Corvallis

Residential zones	Total acres	% of each zone	Vacant area in acres	% of each zone vacant
Low-density (R-3.5, R-6, R-5)	913	38.65	331.22	59.26
Medium density (R-9)	799.97	33.87	147.46	26.38
Medium-high density (R-12)	386.74	16.37	66.9	11.97
High density (R-20)	254.47	10.77	4.33	0.77
Other residential (Mixed use residential)	9.13	0.38	8.97	1.6
Subtotal residential	2,362.13		558.88	

Source: Data from City of Corvallis (2020).

by EcoNorthwest, over 45% of Corvallis households are under housing stress. In terms of tenure, around 25% of homeowners are stressed and approximately 67% of the renter households can be classified under housing burden as well, given the traditional 30% housing affordability rule.

The Land-use Development Code (LDC) for the city also discourages mixed-use or high-rise development by restricting these activities in small zones that are already filled up and have little or no space for future construction. For example, only 27% of the residential land allows high- and medium-high density residential added together and less than 1% is reserved for mixed-use residential (Tables 1 and 2 and Fig. 6). Hence, developers choose single-family detached over multidwellings or apartment buildings, with the sole aim to minimize development cost while maximizing profit and ease of building. This has caused a vast mutilation of the city's sustainable housing options in the current urban planning scenario.

To further investigate these housing issues, informal talks with urban planners, economists, developers, and community interest groups of the area were conducted. These discussions targeted on identifying the primary issues within Corvallis related to housing affordability and the efforts made by each of the organization in resolving the same. Moreover, an expert insight was sought into the indicators effecting housing affordability in the local context. The prospects of cluster/cottage housing in the city were also discussed as an infill development strategy.

In an effort to define the background realities of housing stress in the city, two main policy issues were identified. The first cause underpinning this situation is an upfront shortage of buildable land especially in the high-density zones and other cause is the resistance to increase the supply of this land by the current Corvallis residents. The scarcity of land for housing is basically a product of difficult topography and the vote of annexation in Corvallis. Most of the projects for annexation have been rejected by the community, making it increasingly difficult for city managers to arrange buildable land to attract developers. These dual intricacies work both individually and combined to determine the overall pressure on housing in the city. Consistent with the aforementioned debate, the representatives from Benton County for Humanity identified resistance of current residents toward having a low-income community in the neighborhood as the main hurdle interacting with broader urban dynamics of affordable housing. There is an apparent trend among the residents to maintain the status quo to keep the city small through voting against the plans for the city's expansion. Most of the annexation proposals for north Corvallis typically do not get through but some do make it for the southern parts of the city, chiefly attributing to the fact that the southern housing market is predominantly renter occupied. The situation is further compounded by the lack of provision for high-rise, high-density, and mixed-use zones in the LDC. A minimal share of 1.7% of the high-density zone is vacant, leaving a little hope for the developers to plan high-rise condominiums for the ever-increasing student

Table 2. Residential density in Corvallis

Zone	Density	Allowed housing type
RS-1 (Very low density)	0.5–2 units/acre	Single-detached
RS-3.5, RS-5 and RS-6 (Low density)	2–6 units/acre	Single detached, townhouse, duplex and triplex only
RS-9 (Medium density)	6–12 units/acre	Single detached, townhouse (three to five units) duplex and multidwelling—triplex and fourplex only
RS-12 Medium-high density	12–20 units/acre	Single detached, townhouse, duplex and multidwelling
RS-20 High density	Over 20 units/acre	Single detached, townhouse, duplex and multidwelling
RS-12 and RS 20MUR Mixed use residential	Over 12 units/acre	Single detached, townhouse, duplex and multidwelling in a residential-only development—minimum density of 20 units/gross acre

Source: Data from City of Corvallis (2006).

population of Oregon State University (Corvallis Gazette-Times 2018). The city council has been trying to find acres that they can rezone into mixed use and high-density residential but with little success.

Equally significant, however, is the recognition that the LDC provides strict guidelines on the accessory dwelling units for the existing housing. Moreover, developers find it difficult to comprehend the hard and complex language of the document, thus their attention gets diverted toward neighboring cities such as Philomath and Lebanon, where the regulations are comparatively relaxed. Although, the zoning plan does allow for a few future residential pockets for the city, difficult elevation poses another problem to the availability of buildable land. The relief of the city includes patches classified as wetlands, chunks of residential land requiring excessive grading (including cutting and filling), and difficult elevation. The prerequisite to work against gravity in few areas entails the use of pressure systems that can result in complications if power goes out (e.g., pumping sewage). In addition to being prone to natural disasters, this high elevation raises the costs of utilities and the related infrastructure. Furthermore, there are many residential lots flagged as vacant due to their challenging shapes and sizes. Yet, above and beyond all these glitches, there is good news: large land parcels are under single ownership, which may make it easier for a developer to buy and build on. A few examples include the Ponderosa and the Timberhill lots.

The ready-built houses are the most favorable choice to buyers in the market. Vacant lots generally rank low on their priorities due to the long procedures for approval and construction. Although move-in-ready cottage cluster growth can be a feasible preference to cater the housing needs, it fails to fasten the developers' attention

J. Urban Plann. Dev., 2021, 147(1): 04020054

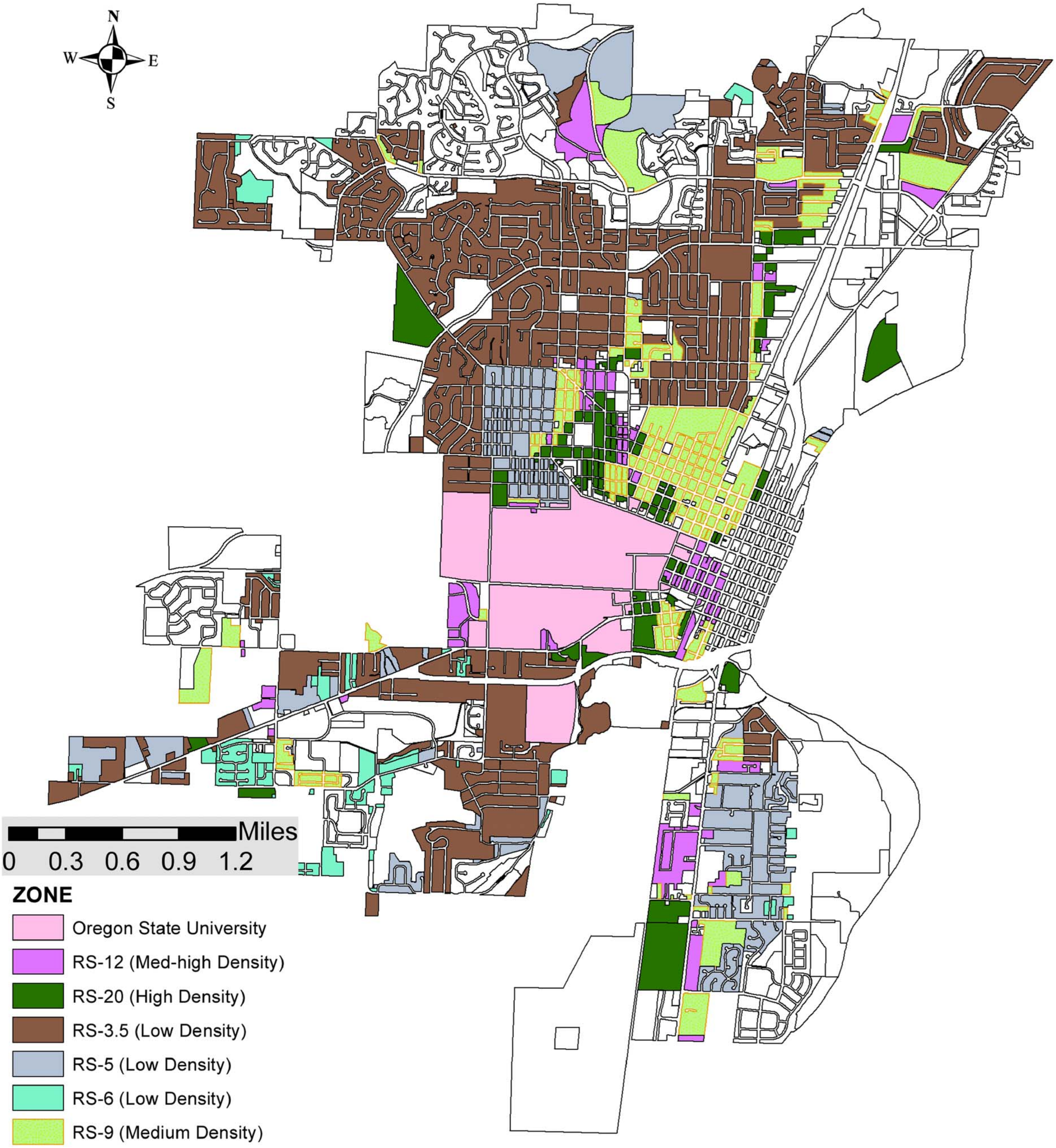

Fig. 6. (Color) Land use map of Corvallis showing current residential zones, with planned development itemization (Benton County GIS 2018). (Data courtesy of City of Corvallis 2020.)

due to low profit margins. Incentivizing such measures through density bonuses, tax evasions, and fee reductions will boost or at least contribute toward some of the residential projects and investment costs. Altering some LDCs (for at least the flag lots) to favor cluster/cottage housing will help address the shortage issues to some extent.

The City of Corvallis should make all efforts to increase the affordability of quality housing stock. In this concern, an infill task force should work on the increase of land supply through promoting cottage cluster development, especially on the flagged lots. Moreover, policy structure should be relaxed to accommodate accessory dwelling units, and residents interested in building small units (similar to tiny, portable homes) on their property/in their backyards should be incentivized through tax breaks. Responding to the market demand, there should be wide-ranging solutions to choose from and this variety will help match the pockets of diverse income groups. High-density, smaller homes, high-rise for students and cottage clusters for the elderly, empty nesters, and young couples can be a few viable options.

Analysis

The methodology for housing stress analysis can be categorized into three different steps: selection of the target indicators and data gathering, conversion of the data from vectors to rasters and finally the execution of overlay analysis on the target characteristics (Fig. 7).

The initial step involves data selection. Parameters to quantify the pressures on housing were finalized after a thorough literature review and discussions with the policy professionals. This selection was somewhat limited due to the inaccessibility of spatial data, so this step involved the collection of GIS shapefiles and the conversion of other data files to suit the ArcMap environment. However, after a rigorous episode of debates the final collection of "measures of housing stress" also termed "Target shapefiles" (Fig. 7) was made: income and education level of the residents was used to measure the housing affordability criteria (Tables 3 and 4); age and condition of residential structures were selected as a gauge to the condition of current housing; and "commuting time to work" was chosen as the final tradeoff people make on adequate housing. However, the authors contemplate that wherever and whenever available, spatial data on the monthly/annual mortgage payments, rents, utilities, and insurance for the households should also be added to stress mapping. Adding these variables would increase the reliability of the findings (Table 4).

With the increasing prevalence of GIS data in the real estate profession, GIS data has become easily accessible through open web access, hence the spatial data was collected and compiled for the Corvallis jurisdiction. Most of the current city shapefile data used in this assessment comes from census data tiger files. Depending on the requirements, a combination of data from census tract and block geographies was collected. The census geographies were matched to the city-level boundaries using GIS intersection and area allocation techniques (US Census Bureau 2018b). The first step was to acquire the shapefile for income for the city. Department's Quarterly Census of Employment and Wages, the US Bureau of Labor Statistics, the US Bureau of Economic Analysis-Longitudinal Employer-Household Dynamics (LEHD), Local Employment Dynamics (LED), and Quarterly Workforce Indicators (QWI) data offer unprecedented information about workers, their travel and socioeconomic characteristics, and local economies for the United States. The "On the Map" tool in LEHD data investigates the place of work and residential distributions by user-specified geographies at different levels (census tracts, census block groups, or traffic analysis zones) (US Census Bureau 2018b). It generates maps and its related description that shows a "labor shed" (where workers arrive from, who are employed in the chosen area) and a "commute shed" (where workers are employed, who reside in the selected area). In addition to worker inflows and outflows, the application also provides adjoining details on job and housing area disparities, workers movement, and commuting patterns by specific details of workforce; for example, ages, race, sex, education attainment, earnings, or industry types. "On the Map" tool was used to derive the information for income, education level, and commuting time for the residents of Corvallis for the year 2017. The summary statistics identify the amount of pressure on the existing transportation infrastructure with around 40% of the workers commuting more than 16 km (10 miles) daily as a part of their work trip and approximately 30% travelling even more than 40 km (25 miles) per day (Table 5), indicating that people have chosen to travel more in order to cut down the housing expenses. One of the primary steps toward executing a housing stress analysis is formulating the research design.

Commuting time of residents was also acquired from the real-time mapping available for public-use data from the LEHD program, including the QWI and Job-to-Job Flows (J2J). The geographies can then be exported as shapefiles and are available for download according to structural and file naming schema. The data is available as Comma-Separated Value (CSV) files through the LEHD website's data page at http://lehd.ces.census.gov/data/ as well as through the LED Extraction Tool. Shapefiles can then be used to deliver the mapping purpose in QWI Explorer and Job-to-Job Explorer (Beta). They are created by transforming input shapefiles sourced from TIGER/Line. The geographies are transformed and re-projected to WGS-1984 Geographic Coordinate System and finally the shapefile for resident's income, education, and commuting times were obtained (US Census Bureau 2018b). The tax lots shapefile provided by the city of Corvallis carried the important usable information about "year structures were built" and "the condition of buildings." However, the information for the residential structures was acquired by applying structured queries on the shapefile. Figs. 8 and 9 illustrate the process of the transformation of points shapefiles for the abovementioned indicators, exported to GIS as a shapefile and spatially joined to the land use shapefile for the area.

Extensions necessary for this analysis include Spatial Statistics and Spatial Analyst, which are employed to perform classification, reclassification, and overlay techniques. Subsequently, the collected

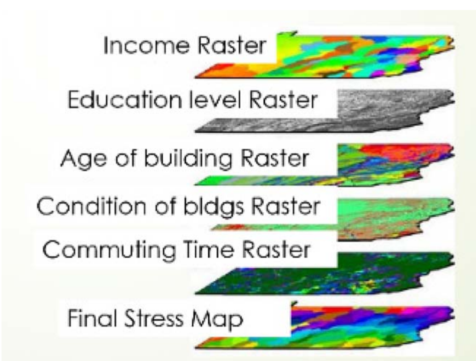

Fig. 7. (Color) Target indicators selection and overlay.

Table 3. Job count for each earnings category

Jobs by earnings (2015)	Count	Share (%)
$1,250 per month or less	5,296	21.5
$1,251 to $3,333 per month	8,613	35.0
More than $3,333 per month	10,717	43.5

Table 4. Job count for each education category

Jobs by worker educational attainment (2015)	Count	Share (%)
Less than high school	1,448	5.9
High school or equivalent, no college	4,695	19.1
Some college or associate degree	6,249	25.4
Bachelor's degree or advanced degree	6,256	25.4

Table 5. Work trips by travel distance

Travel time	Count	Share (%)
Total primary jobs	19,120	100.0
Less than 16 km (10 miles)	11,681	61.1
16–39 km (10–24 miles)	1,712	9.0
40–80 km (25–50 miles)	2,641	13.8
81 km and greater (Greater than 50 miles)	3,086	16.1

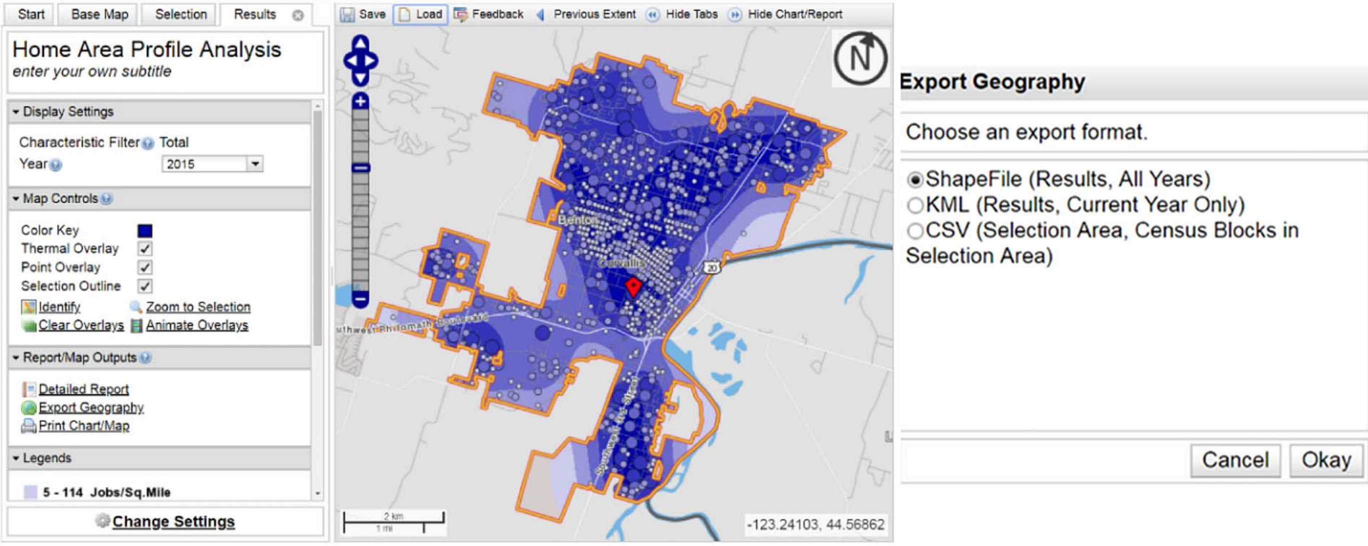

Fig. 8. (Color) "On the Map" home area profile analysis.

Fig. 9. (Color) Spatial join for residents commuting time.

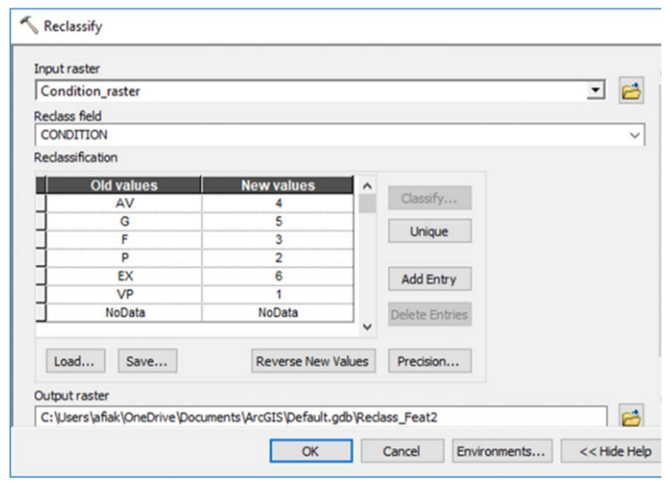

Fig. 10. (Color) Reclassification of the conditions of building raster.

files were converted into raster using raster conversion tools. Reclassification of all the rasters into common scale was done using the reclassify tool. Consequently, the cell values of the original rasters for each of the characteristics were given alternative values using the method of specified intervals. Next, the selected set of rasters was rescaled or reclassified into a common scale as shown in Fig. 10. All rasters are reclassified at a scale of 1–6 with "6" being the highest (worst situation) and "1" being the lowest (best situation) on the scale of housing stress using the score range method, which linearly transmutes the attribute values to ordinal values.

As a next step, five standardized attribute map layers were generated and all of them were converted into a 25 m resolution raster grids, to serve as the input data layers adding to the final stress. This transformation gives an opportunity to do relative weighting under a common overlapping environment. Finally, the overlay analysis was executed to produce the final stress map shown in Fig. 11. Mapping these areas will help pinpoint where housing pressures are maximum. Finally, the zonal histogram was created for each of the residential zone and the method is illustrated in Fig. 12. It displays the frequency distribution of each raster cell on the value input for each unique residential zone for Corvallis.

Results

After the execution of the following five steps in ArcGIS 10.1 Spatial Statistics and Analyst tools, we produced the final stress map and chart:

1. Section and input of the datasets.
2. Vector to raster conversion to derive the required datasets.
3. Reclassification/rescaling of the datasets.
4. Overlay analysis for combing the datasets.
5. Generation of zonal statistics.

This union to combine the attributes of several rasters into one involves giving numeric values to each characteristic. This facilitates the mathematical conglomeration of all the rasters and assigns a combined value to each cell in the output layer. The stress levels on housing can be easily comprehended using the final map in Fig. 11. The lower the stress score on the specified grid, the better

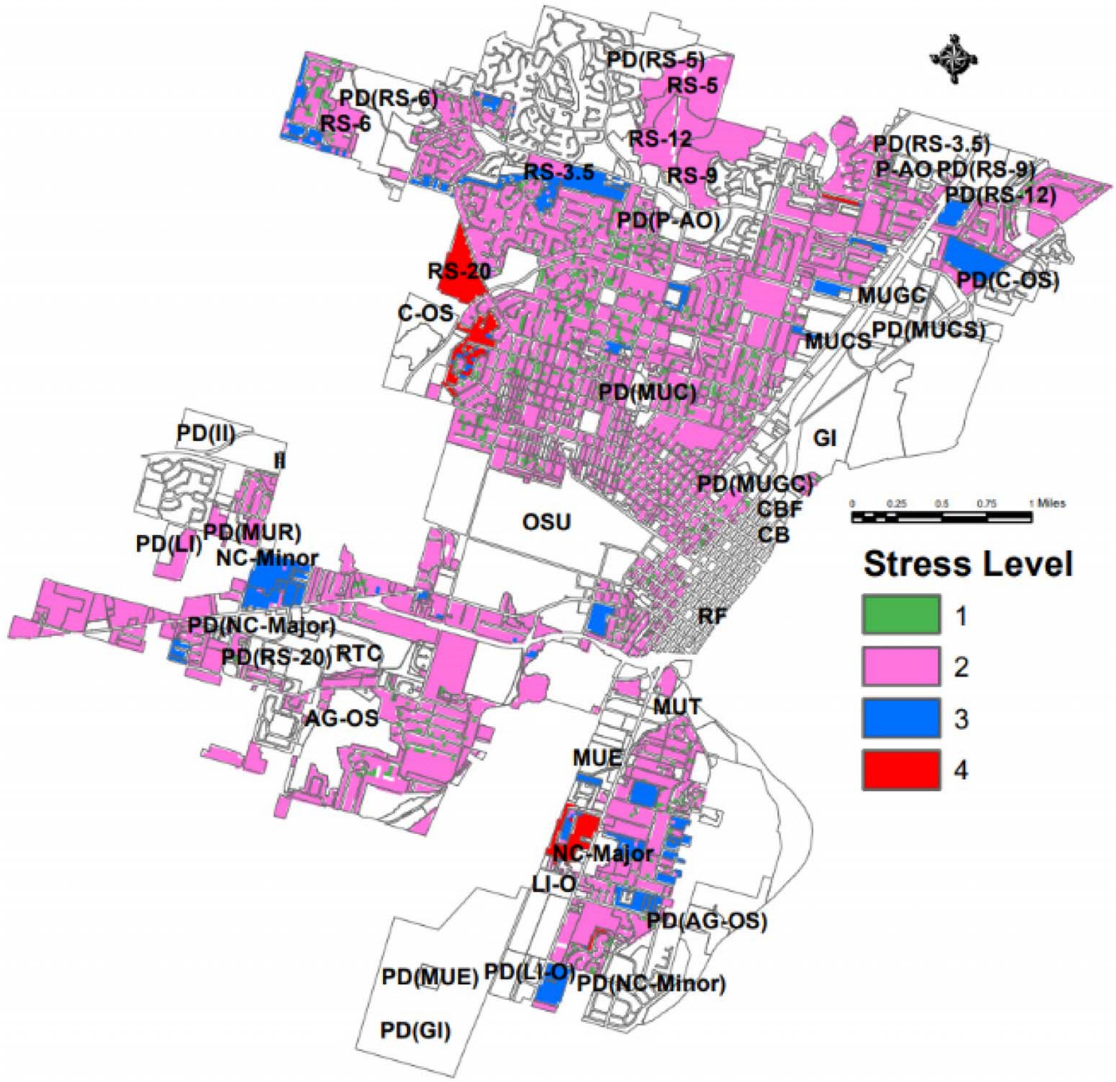

Fig. 11. (Color) Final housing stress map.

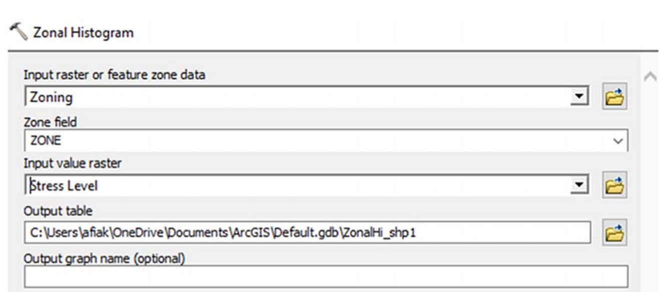

Fig. 12. (Color) Processing of zonal histogram for each residential zone.

the housing in those geographic areas with respect to the selected parameters defined for this research. The most favorable housing units are the ones with lowest stress scores and least favorable are the ones with greatest risk of housing stress.

Stressed housing can also be targeted spatially using the zonal statistics table (Fig. 13), as Zone 3.5 (low-density zone) appears to be highly burdened in terms of housing-related parameters and should be dealt with on a priority basis with immediate effect. In contrast, Zone 6, which is also a low-density zone, has rare occurrences of high-stress levels, indicating that a density based on a one-size-fits-all approach does not work in the housing market. Zone 9 consisting of a variety of housing types including single detached, townhouse (three to five units) duplex, and multidwelling – triplex and fourplex – also has very limited cases of high-stress levels. This sustainable housing type offers a variety of options that suit the affordability of the low- and middle-income population segment of the city.

Contemplating the effects of this spatial deriving, Zone 12 (medium-high density) and Zone 20 (high density) are doing better in terms of stress, the cases of high-level stresses are close to nil yet both the zones do reveal instances of moderate to high stress due to the deteriorating condition of aged housing stock. However, the diversity of the planning issues in each of the residential zone calls for a diagnostic surgery based on the results of this spatial analysis. The preceding section discusses the zone-based remedies and future strategies for Corvallis and links its usefulness to the global urban planning community at large.

Discussion and the Way Forward

The resulting discussion of this research is twofold: the first section suggests the future directions based on the literature review and the

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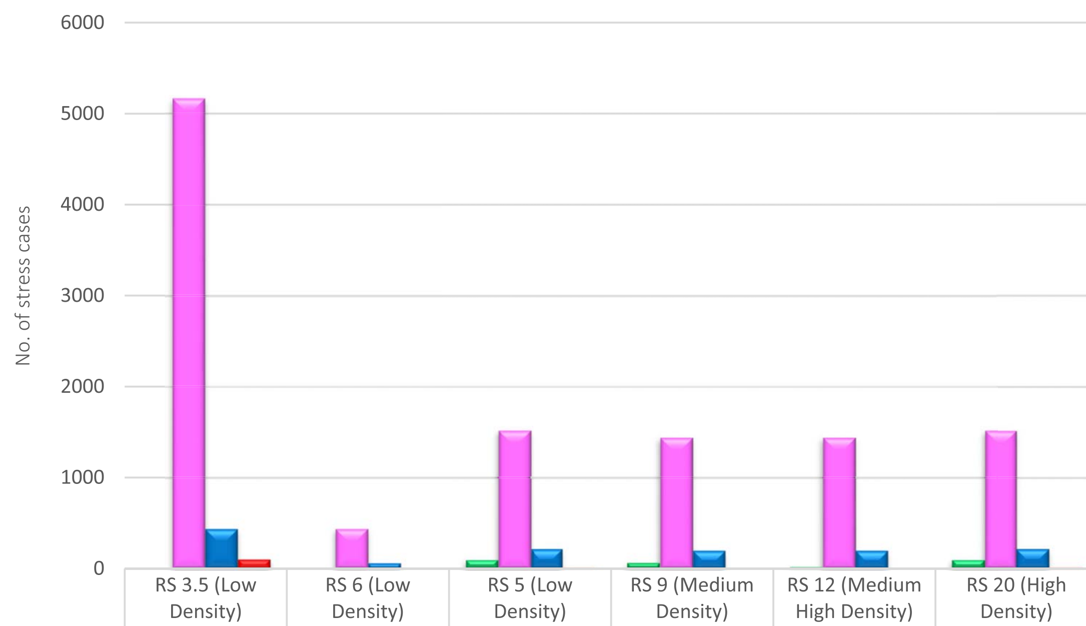

	RS 3.5 (Low Density)	RS 6 (Low Density)	RS 5 (Low Density)	RS 9 (Medium Density)	RS 12 (Medium High Density)	RS 20 (High Density)
Low	0	0	97	64	17	97
Medium	5160	440	1516	1438	1438	1516
High	435	62	218	199	199	218
Very High	104	0	8	0	0	8

Residential Zones showing stress levels

Fig. 13. (Color) Housing stress scores for each residential zone in Corvallis.

interviews; the subsequent part highlights the contribution of the prescribed GIS tool to the urban planning community and its potential applications. The bulk of evidence rationalized in this paper indicates that land supply is limited, job-housing ratio is disturbed, and housing is stressed for Corvallis. The investigation identifies two issues with the housing development broadly: the first one is the scarcity of enough buildable residential land and the other is the inclination of the current zoning plan toward low/medium density residential. In order to address these problems, the remedies should target to amend the annexation policy and the Land Development Code.

Reflecting upon the pivotal mechanisms to housing stress, it can be established that the problem of scarcity of vacant buildable land within the city limits should be resolved on a priority basis because it directly raises the prices of the existing limited residential stock. The entire course of the vote of annexation should be readdressed because all the efforts of plan formulation, environmental impact assessment, and approvals go in vain when the community votes against a development project, which then usually discards a lot of money and the associated efforts. Hence, the other developers are discouraged from following the footsteps of those who spent so much money and time but were rejected at the end. A new policy setting will attract the construction industry to invest in the insufficient housing market of the city.

Furthermore, there is a dire need to revisit the zoning plan for the city because the land-use controls are contributing toward the affordability issues. Planning reforms in the form of mixed-used development and apartment complexes cannot be accommodated in the city due to the hindrances imposed by the LDC. Relaxing the utopian planning laws and rewarding residential development through incentivizing strategies such as density bonuses, fee abdications, and expedited sanctions can be some prolific remedies. This should be achieved through analyzing the final stress map and executing spatially targeted efforts; for example, commercialization of downtown can be included as a policy option whereby the existing residential structures could be converted to more profitable land uses through rezoning them into the business district or commercialized establishments, perhaps allowing commercial activities on the first floor and apartment housing in the ones above. Moreover, for Zone 3.5 (low-density zone) the reforms may include financial assistance programs and incentives to replace the existing inferior old structures with new safe and sanitary housing. "Change of land use" should be considered to make way for more compact housing options reducing the wastage of valuable land in extended infrastructural costs. Soft densification as a planning strategy should also be considered through the additions of "accessory apartments" or "secondary suites" in the current residential stock. Additionally, Zone 12 (medium-high density zone) does allow for a variety of housing types ranging from single-detached to multidwelling. Taking full advantage of this flexibility, high-density structures (multidwelling) should be encouraged using fee waivers, relaxed regulations, and tax evasion strategies. In addition, irregular lots should be allowed for subdivisions making way for pocket neighborhoods and cottage cluster development (this may include zero lot line and allowing dwelling size to go below the current minimum of 1,200 ft^2) for the city.

The strongest appeal of this paper is the development of a scheme to measure the scope and spatial dissemination of housing stress. The tool is particularly different from the typical 30:40 rule that is still used in the literature and is a widely accepted measure for examining the challenges of housing affordability in various parts of the world including Australia and the United States. This approach is highly unsuitable for places such as Corvallis where the residential market consists of big share of renter-occupied student housing with low-income levels. Measuring housing stress via GIS can be principally valuable for urban planning experts throughout the world, given its capability of scrutinizing all conceivable alternative scenarios that would be excessively cumbersome if executed by traditional methods. It assists in an enhanced understanding of the substitute suitability patterns in housing and can assist developing an alternate strategy that includes a range of socioenvironmental factors that can be combined to give the final housing stress scores. The planning authorities worldwide can replace the archaic techniques of measuring housing stress with the prescribed sensible measure. This quick, organized, and efficient method can access the readily available GIS data maintained by most of the municipalities globally. Moreover, it can also help to prioritize the competitive housing projects in the pipeline and improve LDCs for specific density zones.

The given diagnostics surgery can be applied to the existing housing stock in any given area. The resulting stress scores can then assist the policy advocates to gain social, political, and economic support for the type and order of the preferred curative actions. In addition, Housing Stress Analysis can be deployed as a decision-backing tool to help urban planners decide on the future strategies for the provision of adequate housing, thus doing the site suitability prioritization for housing development efficiently. GIS's best contribution to this process would be the identification of those land parcels that are under greatest stress of housing burden such as Zone 3.5 (low density). Yet, in case of Corvallis all low-density residential zones cannot be considered stressed because Zone 6, which is also a low-density zone, does not have many cases of stress altogether.

The analysis most notably shows a mechanism to generate an extensive array of decision policies by incorporating the knowledge of tradeoffs people make to housing costs through transportation and other related costs. In the case of our study area, the workers selected to live in the neighboring cities such as Philomath, Albany, Monmouth, or Salem to overcome the huge housing burden of living in a costly city such as Corvallis. Despite the city offering free public transit to the residents, people still chose to make tradeoffs given the high-end residential market. Thus, strategies such as optimization of residential space through cooperation of the neighboring counties would be worth exploring as well. Such investigation enables the policy analysts and land managers to make judgments and formulate policies in terms of explicit land uses efficiently. The lessons learnt from our analysis support the current notion of sustainable housing practices through neo-urbanism, smart cities, and transit-oriented development because choosing otherwise (low-density sprawl development) would result in high stress levels that would need rectification through infill approaches in future. To sum up, it should be noted that the selection criteria were largely limited due to the availability of data. Increasing the count of housing stress indicators such as housing mortgages, rents, and insurance will help improve the research credibility. Hence, it is acknowledged that this research only provides preliminary guidelines to further develop stress mapping as a tool to assess housing affordability. In addition, similar researches localized to suit specific regions can reap positive outcomes (Fig. 13).

Data Availability Statement

Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request. This includes:

- GIS data: Shapefiles for the city of Corvallis.
- LEHD, LED, and QWI data for Corvallis

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