GOOGLE EARTH ENGINE AND THE USE OF OPEN BIG DATA FOR ENVIRONMENTAL AND CLIMATE-CHANGE ASSESSMENTS: A KOSOVO CASE STUDY

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KEY WORDS: Open data, climate change, environmental change, Google Earth Engine, Kosovo.

ABSTRACT:

This paper presents a framework for utilizing available open data resources, such as Google Earth Engine, to assess environmental conditions and climate change vulnerability in Kosovo. This paper lays the groundwork for academic, government, and private sector institutions to develop strategies for addressing climate change and environmental issues in Kosovo and for other developing nations to understand the extent of change occurring. The study demonstrates the value of open data for environmental sustainability and resilience building. The framework is based on the analysis of air pollution, groundwater monitoring, urban environments, and deforestation in Kosovo using publicly available models. The model is re-coded for Kosovo in JavaScript using open datasets to create an environmental assessment of the scopes and scales of the environmental issues that plague Kosovo. The results show that there is a lack of institutional frameworks for assessing climate change impacts in Kosovo, with limited capacity for conducting environmental assessments, and with limited data capacity for resource and data scarce environments with community managed frameworks. By leveraging extensive amounts of data and applying analytical frameworks, this paper contributes to the knowledge base of environmental conditions in Kosovo with emphasis on open data and technological advancements.

1. INTRODUCTION:

The emergence of new technologies provides opportunities for new methods to broaden the understanding of climate-change impacts as they unfold. The use of these technologies moves a regional understanding of climate change, its impacts, and approaches to develop resilience to a framework that can leverage extensive amounts of data. This paper provides a framework for models that can be used to assess remotely sensed data to untangle the complex web of human-environment interactions and to understand how those interactions will influence global warming and be influenced by change to climates that pose existential threats, particularly to those in data-poor regions like developing countries. These models are functionally different and have environmental links that enable the use of open "big data" to build climate-change resilience with a top-to-bottom understanding of the meaning of the data and the methods of their applications.

This paper discusses the methods of modeling big-data sets in Google Earth Engine to assess both climate change and environmental change. We explore the frameworks for cloud computing of open-data environmental analyses by evaluating data-selection and analytical techniques that may provide a framework for analysis of these problems. By building a cross-sectional understanding of the application of Google Earth Engine to analytical frameworks for resilience-building we hope to traverse governmental and institutional knowledge-building, private sector sustainable development gaps, and public sector environmental and climate development strategies. It is important to emphasize that this paper describes public (open-access) resources that can be used by technically trained analysts to assess environmental change. There is a lack of awareness of the data and tools available and also scant knowledge of their uses for sustainable development and environmental improvements.

An environmental assessment of Kosovo using large and open remotely sensed datasets from Google Earth Engine is explained through a multi-case presentation. Our approach uses publicly available models and code-walkthroughs from the book *Cloud-based Remote Sensing with Google Earth Engine (*Cardille and Clinton et al, 2022). The models were re-coded for Kosovo and the greater western Balkans region in JavaScript using Google Earth Engine open datasets to analyze environmental conditions in this region. This work demonstrates the value of free and open tool development and analysis for achieving environmental sustainability. The use of open data requires careful analytical designs and the application of the correct tools for specific regions and for particular goals. Complex environmental conditions can muddle the results generated from the analyses of open datasets. This assessment attempted here will add to the knowledgebase of the environmental conditions in Kosovo and provides insights into evaluation of the changing climates of the broader region.

Models for air pollution and population exposure, groundwater monitoring, urban environmental quality, and deforestation were connected to data gathered by multiple sensors to create an environmental assessment of the scopes and scales of the environmental issues that plague Kosovo. The air pollution and

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population exposure model assesses the human toll of air pollution in Kosovo. Groundwater monitoring with the Gravity Recovery and Climate Experiment (GRACE) model appraises the health of aquifers and the security of water resources (Purdy, 2019). Urban-environment analysis examines the changes occurring in urbanized parts of Kosovo. The deforestation model is used to determine and evaluate the changes to vegetated environments in Kosovo. Scalability enabled understanding the ways in which interconnected environmental conditions of the Balkans region can be studied further. These models were chosen because water resources, air quality, regional forest cover, and urban land use are of major importance to predicting climate-change impacts and the resilience of a region. The outcomes of these models separately and interactively can help to visualize the impacts of changing climates and the consequences of environmental change in Kosovo.

The methods are interchangeable and replicable for climate-change analysis, sustainability decision-making, and monitoring of environmental change. The study is based on the extent of urbanization in Kosovo in 2020. The air quality and population exposure analysis uses Sentinel-5's TROPOspheric Monitoring Instrument (TROPOMI) data and population density to understand the human health toll of air pollution. The groundwater monitoring application uses GRACE to understand the water storage capacities and trends within the vast aquifers of Kosovo. The forest degradation and deforestation model employs Landsat mission data to map change occurring within the forests of Kosovo over time. Combining these models produces the information needed to analyze the ramifications of the environmental conditions in Kosovo and provide a perspective for understanding the challenges that changing climates portend for the region.

2. MATHERIALS AND METHODS

2.1. Case Study

Kosovo is among the most environmentally degraded countries in Europe. It is also one of the poorest (The World Bank, 2013). The country lacks the capacity to conduct environmental assessments to gauge the scale of its environmental problems. It has even less capacity to understand its vulnerability to climate change and to develop a prognosis for efforts to sustainably develop. Kosovo is in the midst of a frozen conflict with Serbia. The struggle has turned Kosovo from independence-seeker to an economic hostage state. Its developing economy is held hostage by its neighbor and largest trading partner Serbia. Coupled with systemic and systematic corruption within the Balkans region, this has made its people and environments extremely vulnerable to the ramifications of global warming and changing climates.

Much of Kosovo's population relies on communist-built lignite-fired power plants (Wynn G and Flora A, 2020). A lack of reliable energy production and the occurrence of price spikes due to import of power creates a supply-demand gap for firewood where demand is four times the supply (Regional Environmental Center, 2009). This situation leads to deforestation across Kosovo, a predicament exacerbated by urban expansion.

Kosovo's energy production largely relies on two lignite-fired power plants known as Kosovo A and Kosovo B (International Trade Administration, 2016). These plants are located within 3 km of each other in Obilić so they share resources. Together they are known as the Kosovo Power Station. These plants were commissioned in the 1970s and 1980s, respectively (Republic of Kosovo, 2015). Annual lignite production in Kosovo has ranged between 7 million and 9 million tons since 2012 (Wynn G and Flora, A., 2020). The Kosovo B plant contains monitoring equipment to analyze the atmospheric emissions of certain gases and dust. The emissions are not in compliance with the European Union's 2001 regulations because of the antiquated technologies employed used in the plants and due to failure to gauge the long-term energy nee.ds of the population at the time of plant construction (Republic of Kosovo, 2015). In addition to chronic pollutants emitted from these plants, lignite also generates heavy metals that include arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, vanadium and zinc.

2.2. Models:

2.2.1. Air Pollution and Population Exposure: The model, *Air Pollution and Population Exposure*, is used to assess the spatial distribution and probable health impacts of nitrogen dioxide (NO_2) (including damage to respiratory tract and heightened potential for respiratory infections and asthma) to broadly assess the impacts of these emissions. The model employs two datasets: the Sentinel-5P Offline nitrogen dioxide (OFFL NO_2), which reports the density of NO_2 in a vertical column of the troposphere (in mol /m^2); and the Gridded Population of the World Version 4, Revision 11 (GPWv411: Population Count), which models the distribution of population at a resolution of 30 arc-seconds or approximately 1km (Center for International Earth Science Information Network, 2018). . The populations of 28 municipal subregions are also estimated. The resulting equation provides an estimated population exposure for each municipality.

The population-weighted exposure (Exp) aggregated across n pixels for the Republic of Kosovo using Equation 1, where Ci is the NO_2 concentration and Pi is the subpopulation in pixel i.

$$Exp = \sum_i^n \frac{p_i}{\sum_i^n(p)} \, x \, C_i, \tag{1}$$

Where Ci = NO2 concentration

P_i = subpopulation in pixel

i = pixel

2.2.3. GRACE water anomalies detection: The Gravity Recovery and Climate Experiment (GRACE) is a technique that uses two satellites to measure water volumes indirectly based on the gravitational forces of the moon (Wiese, 2015). This model is applied to the Drine i Bardhë (White Drin) basin which flows into the Drine I Bardhë (White Drin) River in Kosovo. A simple regression is used to understand the changing amounts of water stored in the basin.

$$TWS_a = CAN_a + SW_a + SM_a + SWE_a + GW_a, \tag{2}$$

Where TWSa – Total water storage anomalies

CANa – Canopy Storage Anomaly

SWa – Surface Storage Anomaly

SWEa – Snow Water Equivalent Anomaly

GWa – Ground Water Storage Anomaly.

2.2.4. Urban extent: Urban extent was measured with Landsat 7 data compiled between 2018-01-01 and 2020-01-01. A composite image was created using unsupervised classification to estimate the extent of the built environment.

2.2.5. Deforestation: The model for large-scale deforestation was modeled using Landsat data, applying a spectral unmixing algorithm (SMA), which is a method allowing for mixed classification pixels for which the endmembers of GV, NPV, Soil, Shade and Cloud. and the normalized difference fraction index (NDFI) as follows:

$$NDFI = \frac{GVshade - (NPV+Soil)}{GVshade + (NPV+Soil)}, \tag{3}$$

Where GV Shade= shade normalized fraction given by:

$$GVshade = \frac{GV}{100 - Shade}$$

The model implements time functionality to determine if there was an occurrence of no change, logging, deforestation, or regrowth (Souza and Roberts, 2005).

3 RESULTS AND ANALYSIS

3.1. Pollution Population Exposure

NO_2 concentrations have been used as a proxy for other combustion products, the potential for the presence of other toxics and heavy metals, and generally poor air quality for decades (Jarvis and Adamkiewicz, 2010; Evangelopoulos et al., 2020). Other pollutants commonly found with NO_2 include carbon monoxide (CO), and volatile organic compounds (VOCs). These pollutants are also produced by transportation and other industrial activities, and can interact with NO_2 to create secondary pollutants, particularly ozone (O_3) and acid precipitation (nitric acid or HNO_3). Multiple studies have confirmed the associations of human health effects and NO_2 (Choi 2019; Heinrich, 2012). NO_2 also reacts with other atmospheric molecules to form aerosols (considered to be particulate matter (PM)) which have been shown to generate significant health impacts as small diameter aerosols (PM2.5) are respired deeply in the lungs to raise the risks of cancer and have even been found to cross the blood-brain barrier which may cause cognitive decline, dementia, and behavioral problems. Lignite (brown coal) is the dirtiest coal. Emissions of all emission byproducts can become aerosolized and can impact air quality for kilometers. In addition to the aforementioned compounds, multiple aliphatic and aromatic hydrocarbon compounds (including benzo (a) pyrene, dibutyl phthalate, Hydroxy-mehoxy-phenols, naphthalene, and benzenes) have been found in lignite coal (Majaraj, 2014; Perjal, 2014). These components are not monitored at the Kosovo plant, and therefore are often not accounted for during risk assessments. Examinations of other lignite coals in the region have revealed naphthalene to be the pollutant found in the highest concentration (Perjal, 2014). The burning of Kosovo lignite releases high levels of the trace metals arsenic [As], chromium [Cr], nickel [Ni] and mercury [Hg], each of which compounds the impacts of combustion-derived pollutants. The concentrations of these pollutants and their impacts increase as energy production increases (Kittner, 2018). Kosovo has been unable to meet its renewable-energy developmental goals due in part to systemic and systematic corruption, further straining the aging energy systems. This increases the costs of energy imports, deforestation, air and water pollution, and the environmental consequences of pollution in Kosovo.

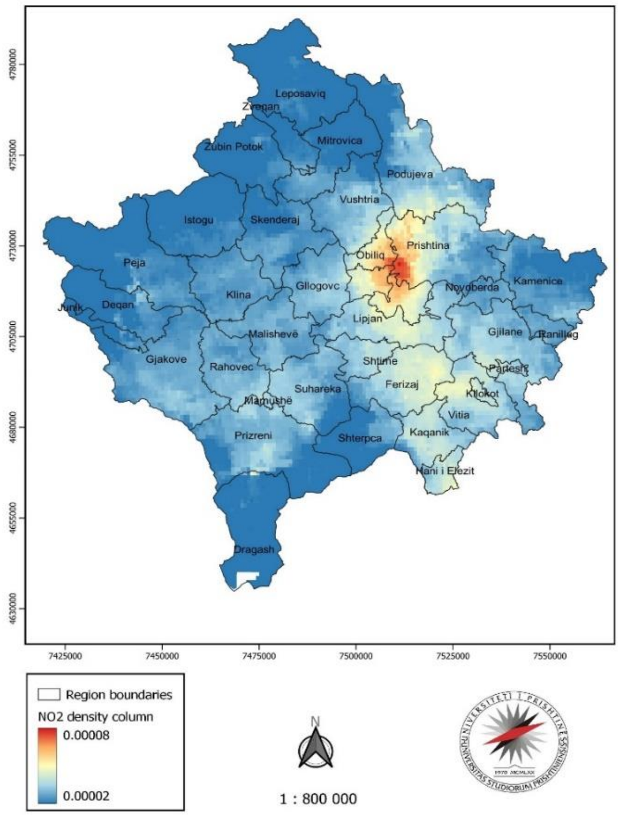

Figure 1. NO_2 from September to December (Winter).

	NO_2 Concentration PopWeighted	Pixel Cover %	NO_2 Concentration Raw
Deçan	0.000193	1057.402	0.000253
Dragash	0.000136	826.003	0.000211
Ferizaj	0.000503	1555.851	0.000537
Fushë Kosovë	0.000992	1522.702	0.001032
Gjakova	0.000307	1366.782	0.000368
Gjilan	0.000363	1249.446	0.000415
Gllogovc	0.000647	1519.523	0.00066
Graçanicë	0.00084	1649.856	0.000873
Hani i Elezit	0.000425	1502.066	0.000451
Istog	0.000246	1154.368	0.00027
Junik	0.000162	946.5912	0.000212
Kaçanik	0.000412	1552.945	0.000454
Kamenicë	0.000273	1349.504	0.000285
Klinë	0.00031	1291.229	0.000339
Kllokot	0.000405	1481.904	0.000413
Leposaviq	0.00025	1411.408	0.000286
Lipjan	0.000648	1554.775	0.000689
Malishevë	0.000461	1480.427	0.000484
Mamusha	0.000558	1400	0.000546
Mitrovicë	0.00035	1492.08	0.000399
Mitrovicë Veriore	0.000522	1600	0.00049
Novobërda	0.000405	1316.079	0.000403
Obiliq	0.001013	1505.319	0.001034
Partesh	0.000401	1494.61	0.000433
Peja	0.000223	1058.073	0.000298
Podujeva	0.000351	1377.477	0.000392
Prishtina	0.000589	1375.171	0.000585
Prizren	0.000337	1301.806	0.000419
Rahovec	0.000403	1297.142	0.000559
Ranillug	0.000354	1497.657	0.000383
Shtërpca	0.000224	875.9425	0.000285
Shtime	0.000489	1523.128	0.000505
Skenderaj	0.000399	1492.085	0.000463
Suhareka	0.000439	1457.746	0.000508
Viti	0.00039	1451.348	0.000436
Vushtrri	0.000505	1412.8	0.000523
Zubin Potok	0.000363	1449.695	0.000397
Zveçan	0.000372	1557.417	0.000416

Table 1. NO_2 Concentration weighted to Population.

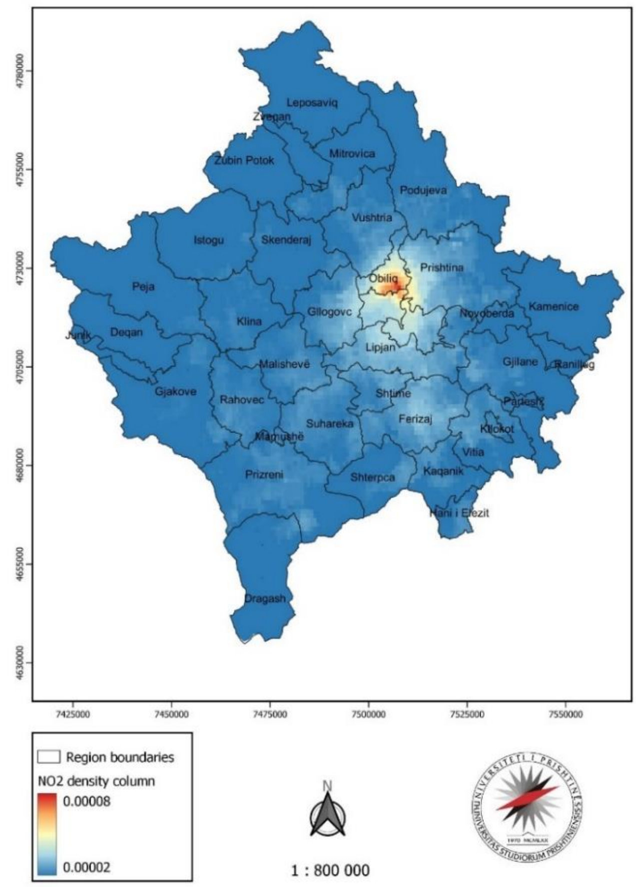

Figure 2. NO_2 from May to July (Summer).

3.2. GRACE

The GRACE Trellis Mass Grids represent the total water (TWSa) measured above and below a baseline based on gravitational anomalies in Kosovo (Figure 3) based on the differences between the mass of land and the mass of water. The amount of water fluctuation in a region is apparent. The thickness of groundwater in Kosovo can been seen varying between the seasons. A regression reveals the trend of water storage in the basin (Figure 4).

Total annualized water storage anomalies (Figure 4) shows that storage anomalies are increasing, which is positive for water security, but bad news for flood risk as urbanization and deforestation are positively related to flooding potential. Precipitation can recharge aquifers, but heavy runoff may produce significant damage even if aquifers and groundwater are not saturated. But once water-storage capacity is reached, any precipitation will runoff and may reach destructive proportions.

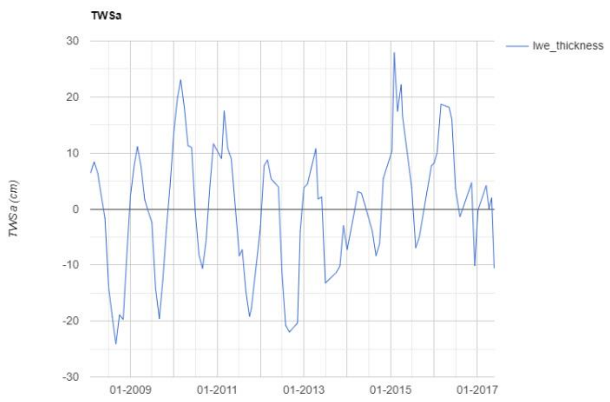

Figure 3. Total Water Storage Anomalies in the Drini i Bardhë.

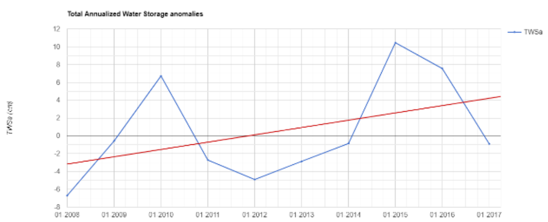

Figure 4. Total annualized water Storage anomalies in the Drini I Bardhë.

The increase in water anomalies within shorter periods is expected in some regions due to changing climate patterns. This appears to be developing within the data for Kosovo. Indications from field interviews of viticulturalists in the Drin i Bradhë basin revealed a developing issue: "too much water at the wrong time and not enough water at the right time." The disparity between water demand and water availability is the growing threat to agriculture in Kosovo. Rising mean temperatures at higher elevations create the problem of increased snow melt earlier in the spring, reducing the availability of water resources in the basin later into the spring, summer, and autumn seasons. The water supply in August (the warmest month of the year) has already reached a deficit of 8% (Fang, 2010). As water demand increases due to higher temperatures earlier in the year, this monthly deficit will grow. Urban areas, industry, and agriculture in the region will come under increasing duress.

3.3 Urbanization

Urban development in Kosovo largely bypasses legal systems. There is an absence of centralized control to address housing and other needs. This has led to a proliferation of illegal and dangerous development. The process of unregulated and unsustainable building practices increases deforestation, water demand, water pollution, and energy consumption. The cycle and feedback loops of environmental degradation and growing susceptibility to changing climates is enhancing the disaster potential of one of the most vulnerable countries in Europe.

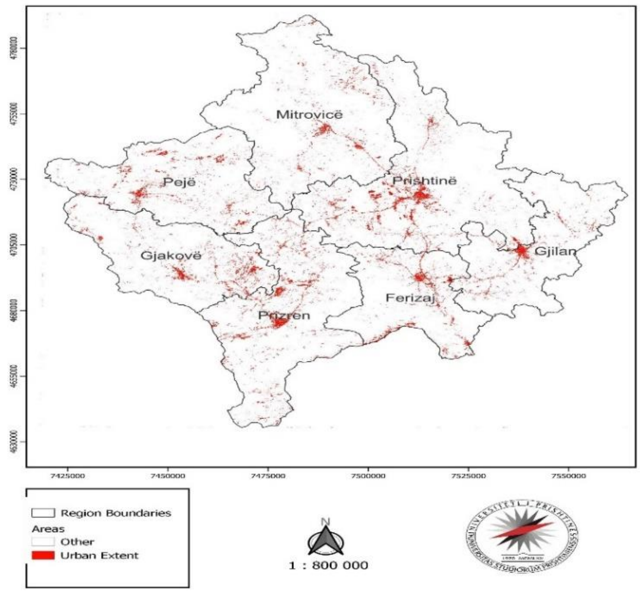

Figure 5. Landsat 7 urban extent detection.

Region	Urban Area (ha)	Urban Area (%)
Ferizaj	4412	11.5
Gjakovë	5003	13.0
Gjilan	3363	8.8
Mitrovicë	4114	10.7
Pejë	4921	12.8
Prishtinë	9010	23.5
Priszren	7527	19.6
SUM	38352	

Table 2. Landsat 7 urban Extent by hectare.

3.4. Deforestation

Rapid deforestation is visible in central Kosovo between Prishtina and Ferizaj, the most rapidly developing area within the country. Deforestation is occurring more rapidly in areas with some urbanization than in areas with little urbanization. This can be explained by the accessibility of forests near populated areas. The west side of Gjilan and the west of Gjakove are likely being deforested by people residing outside of Kosovo. Forests expand towards higher elevations with rising temperatures. Vegetative regrowth is likely in unreachable and high-altitude areas historically not sustainable for growth are becoming suitable with temperature increases new growth will develop in new areas.

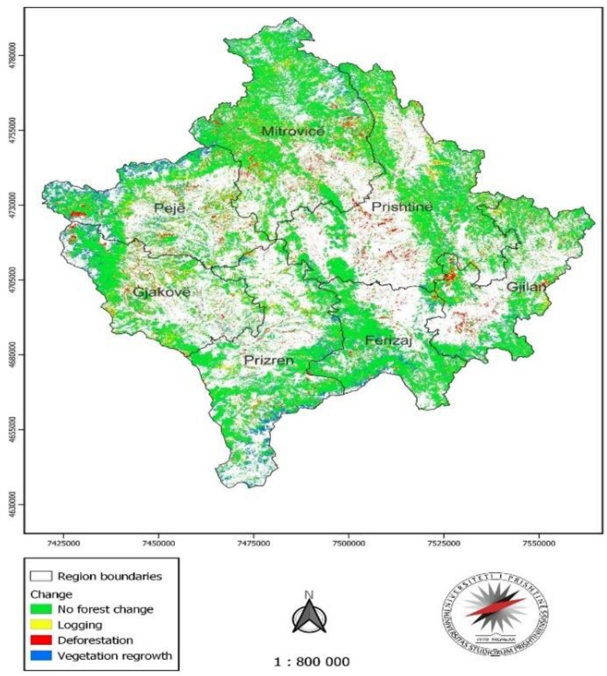

Figure 6. Deforestation in Kosovo.

Region	No forest change (ha)	Logging (ha)	Deforestation (ha)	Vegetation regrowth (ha)
Ferizaj	131349	46179	4061	1780
Gjakovë	187227	38960	10295	4315
Gjilan	194362	41941	7816	4793
Mitrovicë	263198	91829	19285	7806
Pejë	191742	40898	10855	5076
Prishtinë	395184	77997	15390	8324
Priszren	270122	56129	8715	3011
SUM	1633185	393933	76417	35106

Region	No forest change (%)	Logging (%)	Deforestation (%)	Vegetation regrowth (%)
Ferizaj	8.0	11.7	5.3	5.1
Gjakovë	11.5	9.9	13.5	12.3
Gjilan	11.9	10.6	10.2	13.7
Mitrovicë	16.1	23.3	25.2	22.2
Pejë	11.7	10.4	14.2	14.5
Prishtinë	24.2	19.8	20.1	23.7
Priszren	16.5	14.2	11.4	8.6

Table 3. Total hectares by category of deforestation and percentages of total by municipality.

Deforestation is a major issue in Kosovo as there is a lack of enforcement of laws or regulations by a national authority and this is worsened by high demand for forest products (principally wood for energy) (Castillo, 2015). Deforestation is a complex socio-economic issue caused by dire economic conditions. Coping with freezing temperatures during severe winters requires energy. And the losses of forest resources on the frontiers of Kosovo are adding to the strain on forests. This is seen clearly in the Peja, Gjakova, and Gjilan regions along the borders with Montenegro, Albania, and North Macedonia. Heavy deforestation of *Pinus peuce* or the Balkan Pine near Peja (adjacent to Montenegro and Albania) is well known. According to our analysis, the region with the greatest deforestation is the Mitrovice region of the north. This is likely due to the abutting of the legal systems of Kosovo and Serbia in the frontier. Based on data from this study, deforestation in the Pristina area appears to be related to urbanization and the formation of a "Greater Pristina." The cities of Ferizaj and Gjilan have populations of 470,500 and 752,500.

The deforestation model revealed "vegetation regrowth" in the mountainous regions south of Prizren and north of Peja. These are likely extensions of forests into previously unsuitable habitats of the mountains that have become more hospitable for tree growth due to warming and wetting climates (Pearce, 2022). The surface temperatures in those mountainous regions have increased significantly between 2000 and 2020 (Sanchez, 2023). This so-called regrowth may be better labeled "new growth" due to the increasing range of forest species.

The rate of deforestation in Kosovo is unprecedented and unsustainable. Large areas of forest are being illegally logged or simply clear-cut. The environmental impacts of deforestation endanger the long-term resilience to change in Kosovo. Increasing water anomalies are expected to increase as climates change and in combination with deforestation, they will increase the probability of catastrophic flooding and will also facilitate the increased pollution of already polluted water systems.

4 DISCUSSIONS

This paper highlights the importance of access to open resources and geographic data for developing countries for developing an understanding of environmental change that are occurring while addressing sustainability and climate change challenges in Kosovo. The study demonstrates the value of and important for free and open tool development their capacity in providing analysis and tool creation for the development of environmental sustainability strategies. A broad assortment of datasets, models, and analysis were combined to produce a broad understanding of the impacts and changes occurring in Kosovo. This allows for a more comprehensive understanding of the connectivity for environmental conditions.

One key finding of this study is the lack of capacity in Kosovo to conduct environmental assessments and understand vulnerability to climate change and prospects for sustainable development. The use of open data and remote sensing techniques can help bridge this gap by providing valuable insights into environmental conditions and changes in the developing world, with Kosovo specifically such as air pollution, population exposure, groundwater monitoring, urban environments, and deforestation.

It is valuable to emphasize the importance of careful analytical designs and the application of appropriate tools for specific regions and purposes when using open datasets and the understanding of the reliable limitations of these approaches and techniques. The complex connectivity between environmental and climatic changes poses considerable challenges in data interpretation and analysis, and there is a strong need for robust open methodologies, models, and datasets. The models and datasets used are interchangeable through a near global community and replicability of the methods used in this study for climate change analysis, sustainability decision-making, and monitoring of environmental change. The combination of different models and datasets, such as Landsat, MODIS, and Sentinel-5 TROPOMI, allows for a comprehensive understanding of environmental conditions and changes over time.

One key challenge for Kosovo is the lack of awareness and capacity among researchers, policymakers, and stakeholders regarding the availability and potential for satellite datasets. Many are simply not aware of the wealth of satellite data available or lack the technical skills and infrastructure required to effectively access, process, and analyze this data. This can result in missed opportunities for evidence-based decision-making and informed policy development related to environmental sustainability and climate change mitigation and adaptation in Kosovo.

There is immense and untapped potential in utilizing remote sensing and big data analysis in Google Earth Engine for developing academic frameworks, government strategies, private sector initiatives, and public sector policies for resilience building in the face of climate change impacts. Furthermore, the development of open statistical framework with community-based solutions would immensely promulgate the use capacity for the troves of global datasets that largely go underutilized. There is an immense importance of the significance for leveraging extensive amounts of data to understand human-environmental interactions and their implications for developing nations facing existential risks from climate change.

We are experiencing no shortage of problems from climate and environmental change that would benefit from a broader open data resources and analysis toolkits. Including improved data access and a community capacity for decentralized data management on open-source analytical tools with the goal of enhanced data transparency and accountability. This framework provides tools which support data-driven decision making in the face of the unfathomable challenges occurring throughout social and economic structures. Moving forward is an incredible opportunity to develop open-source decentralized datasets and code-based analysis tools that will empower developing countries in the fight against climate and environmental change.

The utility of the open-data and models were hit and miss as some datasets were not scaled correctly or were highly contaminated. Further enforces the need for user-based solutions community decision making for corrections which address underlying data issues, when possible.

5 CONCLUSIONS

In conclusion, Kosovo faces significant environmental degradation and poverty, with limited capacity for conducting environmental assessments and is missing institutional frameworks for understanding climate and environmental change impacts. We have presented a framework for utilizing available open data resources, such as Google Earth Engine, to assess environmental conditions and climate change vulnerability in Kosovo. Using models for air pollution, groundwater monitoring, urban environments, and deforestation, this paper demonstrates the value of open data for environmental sustainability and resilience building. The code for the models is available in an open book, we highlight the potential of new technologies in providing opportunities for understanding the impacts of climate change and developing strategies for resilience.

Further we present an argument for an opensource decentralized analysis tool with design to increase data capacity of resource and data scarce environments with community managed frameworks. By leveraging extensive amounts of data and applying analytical frameworks, this paper lays the groundwork for academic, government, and private sector institutions to develop strategies for addressing climate change and environmental issues in Kosovo and a framework for other developing nations to understand the extent of change occurring. The use of remote sensing data provides a top-to-bottom understanding of complex human-environment interactions and their implications for climate change resilience. Overall, this paper contributes to the knowledge base of environmental conditions in Kosovo and emphasizes the importance of open data and technological advancements in addressing climate change challenges.

ACKNOWLEDGEMENTS

Dustin Paul Sanchez gratefully acknowledges financial support for this publication by the Fulbright U.S. Student Program, which is sponsored by the U.S. Department of State and American Councils Kosova. Its contents are solely the responsibility of the author and do not necessarily represent the official views of the Fulbright Program, the Government of the United States, or the American Councils Kosova. The authors would like to acknowledge the work of Agon Nimani for visualizations, the abstract reviewers, and all others that aided in the project.

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