Assessing light pollution in Mongolia: current status and future trends using remote sensing and citizen science data

R.Tsolmon[1*] , D.UlamOrgikh[1], M.Selenge[2]

[1] School of Art and Sciences Physics department, National University of Mongolia, Ulaanbaatar, Mongolia

[2] School of Engineering and Applied Science, National University of Mongolia, Ulaanbaatar, Mongolia

The inappropriate or excessive use of artificial light, known as light pollution, can have serious environmental consequences for humans, wildlife, and our climate (DarkSky.org). Light pollution is a relatively new and less investigated topic in Mongolia. Previously, there was little awareness about its significant negative impacts. To understand the extent of light pollution in Ulaanbaatar, the capital city of Mongolia, we compared it with a city less affected by light pollution. Ulaanbaatar and Tucson, Arizona, USA, were selected for this investigation. Both cities have populations of around one million. We used NASA's VIIRS/NPP Lunar BRDF-Adjusted Nighttime Lights Yearly SQM data to analyze light pollution from 2012 to 2023. ArcGIS applications were employed to map light pollution in the selected cities. The National Observatory Khurel Togoot in Ulaanbaatar is much more affected by light pollution than Kitt Peak National Observatory in Tucson. Ulaanbaatar and its observatory suffer from significant light pollution due to urbanization and uncontrolled lighting conditions. In the Gobi region of Mongolia, cities are expanding rapidly due to mining and urbanization, resulting in uncontrolled lighting. This light pollution poses a significant threat to the visibility of stars and celestial phenomena, making it difficult for astronomers, researchers, and enthusiasts to study and appreciate the cosmos. Monitoring and implementing dark sky protection using satellite data are crucial for preserving the conditions needed for observing the night sky in the Mongolian Gobi desert.

Key words: Light pollution SQM data, BRDF-Adjusted Night time, Observatory, citizen science

I. INTRODUCTION

More than 80 percent of the world's population, and 99 percent of Americans and Europeans, live under sky glow. Despite its seemingly picturesque name, sky glow caused by human activities is one of the most pervasive forms of light pollution (National Geographic). Kyba et al. (2017) reported that the Earth's artificially illuminated outdoor area increased by approximately 2.2% annually between 2012 and 2016, demonstrating the rapid global growth of light pollution. Artificial outdoor lighting that changes natural light conditions in ecosystems and negatively affects living organisms Longcore(2004). Sky glow is the brightening of the night sky, primarily over urban areas, due to electric lights from cars, factories, outdoor advertising, and buildings, effectively turning night into day for those who work and play long after sunset. People living in cities with high levels of sky glow struggle to see more than a handful of stars at night. Light pollution is a global issue. Light pollution maps illustrate how and where our globe is illuminated at night. Vast areas of North America, Europe, the Middle East, and Asia are aglow with light, while only the most remote regions on Earth remain in total darkness. While Mongolia appears to be in one of these dark areas, its capital city, Ulaanbaatar, is experiencing significant light pollution. This

[*] *tsolmon@num.edu.mn*

study investigates the extent of light pollution in Ulaanbaatar and its implications. The findings from this case study can serve as a lesson for other regions of Mongolia, such as the Gobi region, in terms of controlling light pollution for future development. Light pollution is becoming an increasingly important environmental and astronomical issue in Mongolia. Although Mongolia is internationally recognized for its vast open landscapes and naturally dark skies, rapid urbanization, mining expansion, industrial development, and uncontrolled outdoor lighting are causing significant increases in artificial night brightness, especially in Ulaanbaatar and parts of the Gobi region.

II. DATA

Various international institutions have developed numerous maps on light pollution. This study utilized several sources for analysis and visual validation, including DMSP and NASA VIIRS Blue Marble Nighttime Lights Yearly SQM data (Figure 1) and Globe at Night (https://globeatnight.org) (Figure 2) Sky Quality Meter (SQM) data were used to assess night sky brightness and used to measure how bright or dark the night sky is. It measures:sky brightness, sky glow, artificial nighttime light. SQM values are usually expressed in: magnitudes per square arcsecond (mag/arcsec²). This is a standard astronomy unit for measuring night sky brightness The NASA VIIRS/NPP Lunar BRDF-Adjusted Nighttime Lights Yearly SQM dataset was processed in ArcGIS to analyze spatial and temporal variations in light pollution. For visualization and comparison purposes, the nighttime brightness values were normalized into a relative scale ranging from 0 to 2.5. Higher values correspond to areas with stronger artificial nighttime illumination and greater light pollution intensity. Globe at Night is an international citizen science program that measures night sky brightness and light pollution around the world. It allows ordinary people, students, teachers, amateur astronomers, and the public to participate in scientific observations of the night sky Walker 2020. The project is organized by NOIRLab and international astronomy partners. In the Globe at Night program, participants observe the night sky from their location and compare the visible stars with standard star charts. Based on how many stars are visible, the brightness of the night sky and the level of light pollution can be estimated.

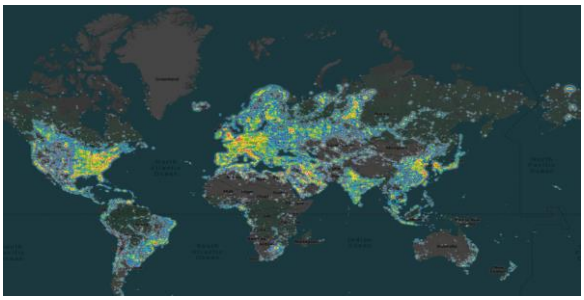

Figure 1. NASA VIRS data

Figure 2. Globe at Night /citizen science data

III. STUDY AREA

Ulaanbaatar is the capital and most populous city of Mongolia, with a population of 1.6 million. It is the coldest capital city in the world by average yearly temperature, situated at an elevation of about 1,300 meters (4,300 feet) in a valley on the Tuul River. The city experiences warm summers and long, bitterly cold, dry winters. The climate is extreme, with summer temperatures reaching up to 73 °F (23 °C) and the coldest January temperatures, usually just before sunrise, ranging between −36 and −40 °C (Figure 3). Tucson is the second-largest city in Arizona, with a population of 1,043,433 The city's elevation is 2,643 feet (806 meters) above sea level. Summers in Tucson are characterized by average daily high temperatures between 98 and 102 °F and low

temperatures between 71 and 77 °F (22 and 25 °C). Early summer features low humidity and clear skies, while mid- and late summer are marked by higher humidity, cloudy skies, and frequent rain. (Figure 4) South Gobi is an aimag (province) of Mongolia, located in the south of the country, in the Gobi Desert. Umnugobi is Mongolia's largest aimag. Dalanzadgad, the capital, is a city in the Gobi undergoing urbanization and was also selected for light pollution analysis. The province is rich in mineral deposits, including gold and copper. Agriculture is of minor importance. As the aimag has various sights to offer, tourism is gaining importance. Umnugobi includes several well known tourist dark sky areas, including the Flaming Cliffs, Gobi Gurvansaikhan National Park and Khongoryn Els - The Singing Sand Dunes (Figure 5).

The locations of Kitt Peak National Observatory in Tucson and Khurel Togoot National Observatory in Ulaanbaatar were analyzed for light pollution. Until 2017, Ulaanbaatar had lower levels of light pollution compared to Tucson. However, after 2017, light pollution in Ulaanbaatar increased significantly compared to Tucson. There is no significant light pollution around Kitt Peak National Observatory in Tucson, while Khurel Togoot National Observatory in Ulaanbaatar is located in a light-polluted area. Light pollution less in the Southern Gobi (Figure 6).

IV. METHODOLOGY AND ANALYSIS

The air pollution map (Light Pollution Map) was used for this study. Ulaanbaatar, Mongolia (Figure 3), and Tucson, Arizona, USA (Figure 4), were selected for light pollution measurements. Both cities have populations of about one million.

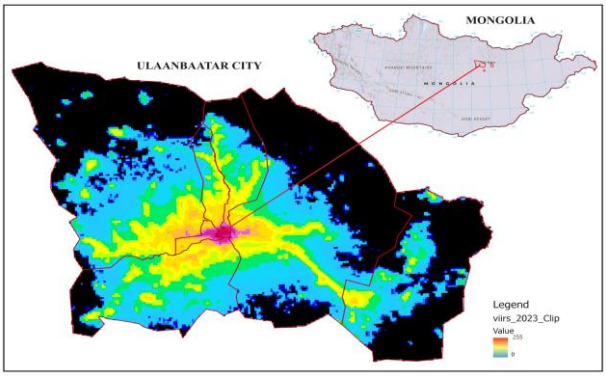

Figure 3 Light pollution in Ulaanbaatar

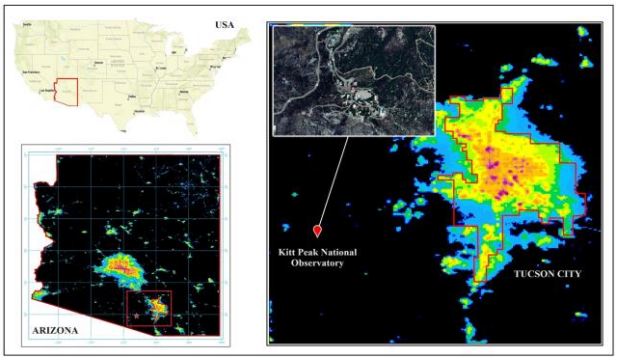

Figure 4 Light pollution in Tucson Arizona

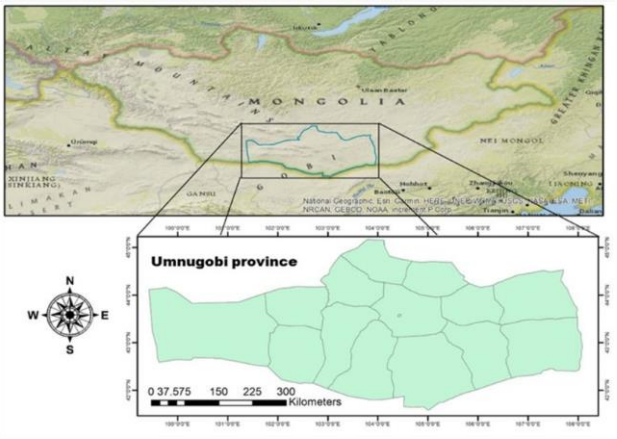

Figure 5 Study area in Gobi region

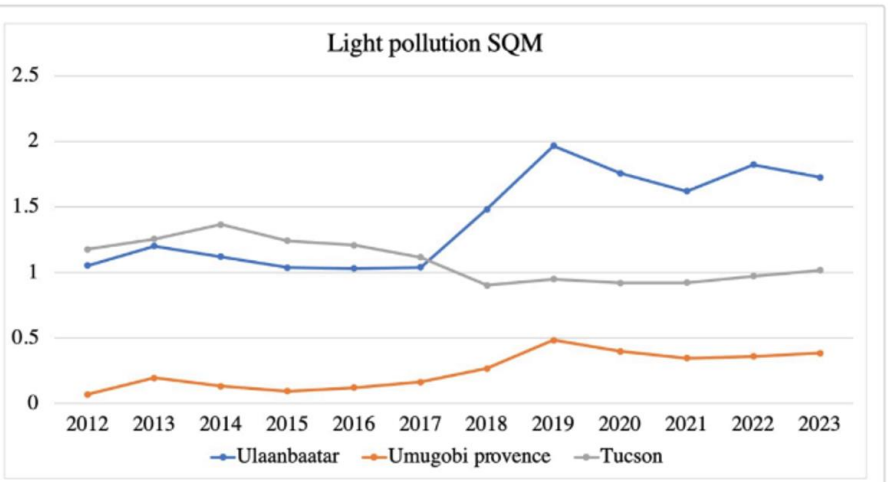

Figure 6 Comparison light pollution in the Ulaanbaatar, Tucson and Umnugobi

V. RESULTS AND DISCUSSION

Based on the analysis of light pollution maps from remote sensing: Light pollution tends to be higher in industrialized nations compared to the developing world. However, noteworthy exceptions exist, with some heavily polluted areas found within countries not exhibiting significant light pollution on the map. Conversely, some countries with overall high light pollution levels have regions devoid of any light pollution. These findings highlight the importance of considering localized factors when estimating total light pollution for each country. There appears to be a lack of awareness among the local population in Mongolia regarding the significance of preserving clear, dark skies and the detrimental impacts of light pollution. Initiatives such as Astro-Ecology education activities could play a crucial role in raising awareness about light pollution and its consequences. The study already demonstrates that light pollution in Ulaanbaatar has increased rapidly after 2017 and that Khurel Togoot Astronomical Observatory is now located within a significantly light-polluted area.

With mining and urbanization driving expansion and uncontrolled lighting in the Gobi, similar light pollution challenges are emerging as those faced by Ulaanbaatar, the capital of Mongolia. Historically, there has been limited awareness about light pollution and its significant negative impacts. This study serves to educate the people of the Gobi about light pollution and its effects, urging them to consider these impacts in their regional development plans. Furthermore, the insights gained from this study can assist decision makers in planning and developing future cities with minimal light pollution from inception.Continuous monitoring of light pollution in Mongolia is essential for protecting dark skies, supporting astronomy, preserving ecosystems, promoting sustainable development, and ensuring that future urban and mining expansion occurs with environmental responsibility.

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Зайнаас тандан судлал болон шинжлэх ухааны иргэдийн мэдээлэлд тулгуурлан Монгол Улс дахь гэрлийн бохирдлын өнөөгийн төлөв байдал, цаашдын өөрчлөлтийн чиг хандлагыг үнэлсэн судалгаа

Р.Цолмон[1], Д.Улам-Оргих[1], М.Сэлэнгэ[2]

[1]Монгол Улсын Их Сургууль, Шинжлэх Ухааны Сургууль, Физикийн тэнхим, Улаанбаатар, Монгол Улс
[2]Монгол Улсын Их Сургууль, Инженерчлэл, технологийн сургууль, Улаанбаатар, Монгол Улс

Хураангуй: Хиймэл гэрлийг зохисгүй эсвэл хэт их ашигласнаас үүдэлтэй гэрлийн бохирдол нь хүн төрөлхтөн, зэрлэг амьтан, ургамал болон дэлхийн уур амьсгалд ноцтой сөрөг нөлөө үзүүлдэг (DarkSky.org). Гэрлийн бохирдол нь Монгол Улсад харьцангуй шинэ бөгөөд төдийлөн судлагдаагүй асуудлын нэг юм. Монгол Улсын нийслэл Улаанбаатар хотын гэрлийн бохирдлын нөхцөл байдлыг үнэлэхийн тулд гэрлийн бохирдолд харьцангуй бага өртсөн хоттой харьцуулсан судалгаа хийв. Судалгаанд хүн амын тоо ойролцоо буюу нэг сая орчим хүн амтай Монгол Улсын Улаанбаатар хот болон АНУ-ын Аризона мужийн Тусон хотыг сонгон авсан. Гэрлийн бохирдлын өөрчлөлтийг 2012–2023 оны хооронд судлахдаа NASA-гийн VIIRS/NPP Lunar BRDF-Adjusted Nighttime Lights Yearly SQM өгөгдлийг ашигласан. Сонгосон хотуудын гэрлийн бохирдлын тархалтыг зураглахад ArcGIS программ хангамжийг хэрэглэв. Судалгааны үр дүнгээс харахад Улаанбаатар хот дахь Хүрэлтогоотын Одон орон судлалын төвийн ойролцоо газар нь Тусон хотын Китт Пик Үндэсний Одон орон Судлалын Төвийн ойролцоох газраас хавьгүй их гэрлийн бохирдолд өртөж байна. Хотжилт эрчимтэй нэмэгдэж, гэрэлтүүлгийн зохицуулалт хангалтгүй байгаагаас Улаанбаатар хот болон түүний ойр орчмын ажиглалтын бүсүүд гэрлийн бохирдлын ноцтой асуудалтай тулгарч байна. Монголын говийн бүс нутагт уул уурхайн хөгжил, хотжилтын өсөлтөөс шалтгаалан хот суурин газрууд хурдацтай тэлж, хяналтгүй гэрэлтүүлэг нэмэгдэж байна. Үүний улмаас үүсэж буй гэрлийн бохирдол нь одод болон бусад огторгуйн биетүүдийг ажиглах боломжийг бууруулж, одон орончид, судлаачид болон сонирхогчдын сансар огторгуйг судлах, танин мэдэх үйл ажиллагаанд томоохон саад учруулж байна.Иймээс Монголын говийн бүсийн шөнийн тэнгэрийг ажиглах нөхцөлийг хадгалан хамгаалахын тулд хиймэл дагуулын өгөгдөлд суурилсан гэрлийн бохирдлын тогтмол мониторинг хийх, мөн харанхуй тэнгэрийг хамгаалах бодлого, арга хэмжээг хэрэгжүүлэх нь нэн чухал юм.

Түлхүүр үг: Гэрлийн бохирдол, SQM мэдээ, BRDF- шөнийн гэрлийн мэдээ, иргэний шинжлэх ухааны мэдээ