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yo'ldoshidan foydalanib olingan tahliliy natijalar, me'yoriy vegetatsiya farqi indeksi (NDVI) samarali vosita ekanligi aniqlandi.

Foydalanilgan adabiyotlar:

1. O'zbekiston Respublikasi Vazirlar Mahkamasining «Ma'muriy-hududiy birliklar chegaralarini belgilash, yer resurslarini xatlovdan o'tkazish hamda yaylov va pichanzorlarda geobotanik tadqiqotlarni o'tkazish tartibini yanada takomillashtirish chora-tadbirlari to'g'risida»gi 299-son qarori. 2018 yil 23 aprel.
2. O'zbekiston Respublikasi Vazirlar Mahkamasining 2022 yil 14 yanvardagi 22-son «Qishloq xo'jaligiga mo'ljallangan yerlarda monitoring ishlarini amalga oshirish to'g'risida»gi qarori.
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RIVOJLANAYOTGAN MAMLAKATLARDA BARQAROR O'RMONLARNI BOSHQARISH UCHUN MASOFADAN ZONDLASHDAN FOYDALANISH

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Annotatsiya. *Barqaror o'rmonlar – bu samarali va ko'p funksiyali, har doim o'zgarib boradigan ehtiyojlarni qondira olish imkoniyatiga ega bo'lgan tiklanadigan resurslardir. O'rmonlarga sarmoya kiritish ijtimoiy va ekologik chidamlilikni mustahkamlashga olib keladi, chunki o'rmonlar tuproq va suvni saqlash, karbonni yutish, yashash joylarini ta'minlash kabi muhim vazifalarni bajaradi. Barqaror Taraqqiyot Maqsadi 15 o'rmonlarni barqaror boshqarishni, degradatsiyaga uchragan ekotizimlarni tiklashni va qayta o'rmonlashtirishni qo'llab-quvvatlasa-da, o'rmonlarning kesilishi davom etmoqda, ayniqsa rivojlanayotgan mamlakatlarda. Bu mamlakatlarda o'rmonlar tez o'sayotgan*

aholi va mahalliy turmushni qo'llab-quvvatlash uchun zarur. Shu sababli, o'rmonlarni boshqarishda yaxshilanishlar zarur. Masofadan zondlash texnologiyasi o'rmon barqarorligini kuzatish va o'rmonlarning kesilishi hamda degradatsiyasini aniqlash uchun samarali vosita sifatida qo'llanilmoqda. Ushbu texnologiya o'simlik qoplamini xaritalashda va o'rmonlarni mahalliy va global miqyosda kuzatishda yordam beradi. Maqolada masofadan zondlash texnologiyasining o'rmon tadqiqotlaridagi roli, shuningdek, ochiq ma'lumotlar siyosati va bulutli hisoblashda erishilgan yutuqlar rivojlanayotgan mamlakatlarga o'rmonlarni xaritalash va kuzatishda imkoniyatlar yaratgani muhokama qilinadi.
Kalit so'zlar: *Barqaror Taraqqiyot Maqsadi 15, masofadan zondlash, barqaror o'rmon va GIS.*

Аннотация. *Устойчивые леса — это возобновляемые ресурсы, которые являются эффективными, многозадачными и способны удовлетворять постоянно изменяющиеся потребности. Инвестиции в леса способствуют укреплению социально-экологической устойчивости, поскольку леса выполняют важные функции по сохранению почвы и воды, поглощению углерода, обеспечению мест для жизни и поддержке средств к существованию. Хотя Цель устойчивого развития 15 поддерживает устойчивое управление лесами, восстановление деградированных экосистем и лесовосстановление, вырубка лесов продолжается, особенно в развивающихся странах. В этих странах леса необходимы для поддержки быстро растущего населения и местных средств к существованию. Поэтому необходимо улучшение управления лесами. Технология дистанционного зондирования эффективно используется для мониторинга устойчивости лесов, а также для выявления вырубки и деградации лесов. Эта технология помогает в картировании растительности и мониторинге лесов как на местном, так и на глобальном уровне. В статье обсуждается роль технологии дистанционного зондирования в лесных исследованиях, а также как недавние достижения в области открытых данных и облачных вычислений создали возможности для развивающихся стран в картировании и мониторинге лесов.*
Ключевые слова: *Цель устойчивого развития 15, дистанционное зондирование, устойчивый лес и ГИС.*

Abstract. *Sustainable forests are renewable resources that are effective, multifunctional, and capable of meeting constantly changing needs. Investment in forests contributes to strengthening social and ecological resilience, as forests perform essential functions such as soil and water conservation, carbon sequestration, providing habitats, and supporting livelihoods. Although Sustainable Development Goal 15 supports sustainable forest management, the restoration of degraded ecosystems, and reforestation, deforestation continues, especially in developing countries. In these countries, forests are necessary to support the rapidly growing population and local livelihoods. Therefore, improvements in forest management are essential. Remote sensing technology is effectively used to monitor forest sustainability and detect deforestation and degradation. This technology helps in mapping vegetation cover and monitoring*

forests at both local and global scales. This paper discusses the role of remote sensing technology in forest research and how recent advances in open data policies and cloud computing have created opportunities for developing countries to map and monitor forests.
Keywords: *Sustainable Development Goal 15, remote sensing, sustainable forest, and GIS.*

Kirish. O'rmonlar suv oqimini kamaytirishda, tuproq eroziyasi va bio xilma-xillikni saqlash va himoya qilishda muhim rol o'ynaydi. Biroq, aholi sonining tez o'sishi va iqtisodiy qishloq xo'jaligining rivojlanishi tabiiy o'rmonlarning kesilishiga, degradatsiya va atrof-muhitga salbiy ta'sirlarga olib kelmoqda [1]. Ko'pgina davlatlar tabiiy o'rmonlarga bosimni kamaytirish va yog'och talablarini qondirish maqsadida o'rmon plantatsiyalarini tashkil etadilar. Shunga qaramay, o'rmon resurslariga doimiy bosim kelajak avlodlar uchun o'rmonlarni barqaror boshqarish masalasini yanada muhokama qilishga olib kelmoqda. Bu o'rmonlarni tiklash, qayta tiklash va agrolesoziya amaliyotlariga, masalan, taungya va uy bog'lariga bo'lgan e'tiborni oshirdi [2].

Birlashgan Millatlar Tashkilotining (BMT) Ming yillik Rivojlanish Maqsadlarini ilgari surish maqsadida, 2015 yilda global barqarorlikka e'tibor qaratish uchun 17 ta Barqaror Rivojlanish Maqsadlari (BRM)(Sustainable Development Goals (SDGs)) belgilandi (Birlashgan Millatlar Tashkiloti, 2015). Xususan, SDG 15 (Quruqlikdagi Hayot) barcha turdagi o'rmonlarni barqaror boshqarishni targ'ib qiladi, bu esa o'rmonlarning kesilishini to'xtatish, degradatsiyaga uchragan o'rmonlarni tiklash va global miqyosda o'rmonlarni tiklash va qayta tiklashni sezilarli darajada oshirishni maqsad qiladi. SDG 15 ni amalga oshirish uchun bizga o'rmon hududida nima bo'lganini va hozirgi kunda nimalar sodir bo'layotganini, shuningdek, vaqt o'tishi bilan yuz berayotgan o'zgarishlar haqida aniq ma'lumotlar kerak. Masofaviy zondlash bu jarayonda muhim rol o'ynaydi, chunki u o'rmonning holatini xaritalash va kuzatib borish uchun isbotlangan metod bo'lib, o'zgarishlarni oldindan bashorat qilish uchun o'tgan davrlarda yer foydalanishdagi o'zgarishlar asosida turli darajalarda (global, mintaqaviy va milliy) ma'lumotlar taqdim etadi [3].

Dunyoning ko'pgina muhim tropik o'rmonlari rivojlanayotgan mamlakatlarda joylashgan bo'lsa-da, boshqa o'rmon turlari (masalan, mo'tadil, O'rta yer dengizi, boreal va konifer) so'nggi o'n yilliklarda masofadan zondlash olimlarining ko'proq e'tiborini qozondi [4]. Shuningdek, rivojlanayotgan mamlakatlardagi tadqiqotchilar, tropik o'rmonlarni o'rganish uchun zarur bo'lgan yuqori samarali hisoblash infratuzilmasiga talab qilinadigan texnik mutaxassislik va katta moliyaviy investitsiyalar cheklovlari tufayli qiyinchiliklarga duch kelmoqdalar [5]. Bundan tashqari, tropik o'rmonlarni o'rganish, doimiy yaqin bo'lgan bulut qoplamasi optik tasvirlarning mavjudligini cheklashi [1] hamda masofaviy zondlashning oldindan qayta ishlash talablarining murakkab va vaqtni talab qilishi bilan bog'liq qiyinchiliklarga duch kelmoqda. Biroq, ochiq manbali Yerni kuzatish (E.O.) ma'lumotlarining mavjudligi, ushbu tadqiqot sohasidagi qiyinchiliklarni yengillatmoqda [1]. Masalan, Sentinel sun'iy yo'ldoshlarining yuqori vaqtli chastotasi va konstellyatsiya kuchaytirish imkoniyatlari bulutlar bilan qoplangan tropik hududlarda samarali ishlaydi [1]; [6]; Sentinel'ning Sun'iy apertura radari (SAR) sensori bulutsiz tasvirlarni ishonchli aniqlashni ko'rsatdi [7].

Masofaviy zondlash, machine learning yondashuvlari va vaqt ketma-ketliklarini tahlil qilish global oʻrmon xaritalarini yaratish uchun, shu jumladan oʻrmon oʻzgarishi va oʻzgarishlarga sabab boʻluvchi omillar boʻyicha maʼlumotlar toʻplamlarini yaratishda qoʻllanilgan, bu maʼlumotlar keyingi tahlillar uchun bepul mavjud (1-jadvalga qarang).

1-jadval.

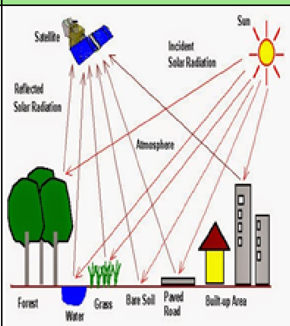
Global yer qoplami maʼlumotlari toʻplamlari

Maʼlumotlar toʻplami	**Vaqt davri**	**Sun'iy yoʻldosh**	**Aniqligi**	**Manba**
University of Maryland Global Land Cover Classification	2009	AVHRR*	1 km	Defries va Hansen (2010)
Global Land Cover Characterization	1992-1993	AVHRR	1 km	Earth Resources Observation and Science (EROS) Center (2017)
Global Land Service	2019	Copernicus	100 m	Marcel va boshqalar (2020)
Land Cover Type (MCD12Q1) Version 6	2001-2019	MODIS**	500 m	Friedl va Sulla-Menashe (2019)
Global forest change	2000-2020	Landsat	30 m	Hansen va boshqalar (2013)
Global Forest Canopy height	2019	GEDI va Landsat	30 m	Potapov va boshqalar (2021)

*Atmosferani boshqarish uchun yuqori aniqlikdagi radiometrik koʻrsatkich, **Moderatli aniqlikdagi tasvir spektroradiometri, ***Global Ekosistem Dinamikasi Tadqiqoti

Koʻpgina global miqyosdagi yer qoplamasi mahsulotlari bioma darajasida belgilangan klassifikatsiyalarni oʻz ichiga oladi [8]. Biroq, katta bioma hududlarida keng tarqalmagan, ammo muhim boʻlgan yer qoplamasi turlari koʻpincha eʼtibordan chetda qoladi. Shunday qilib, global yer qoplamasi maʼlumotlar toʻplamlari mahalliy miqyosda maʼlumotlar yoʻqolishi va xatolarga olib kelishi mumkin, bu esa mintaqalar orasidagi xilma-xillikni yashiradi [9]. Xususan, tropik rivojlanayotgan mamlakatlardagi asosiy agrolesovodlik sinfi boʻlgan uy bogʻlari, mavjud global yer qoplamasi mahsulotlarida [10] kiritilmaganligi sababli, hozirgi adabiyotda bilim boʻshligʻini tashkil etadi. Xususan, uy bogʻlari, tropik rivojlanayotgan mamlakatlardagi asosiy agrolesovodlik sinfi boʻlib, hozirgi adabiyotda bilim boʻshligʻini tashkil etadi, chunki ular mavjud global yer qoplamasi mahsulotlarida kiritilmagan [10]. Bu uy bogʻlari yuqori rezolyutsiyaga ega mahsulotlarni, masalan, 10 m oʻlchamdagi tarmoqni [11] talab qilishi bilan bogʻliq, holbuki mavjud mahsulotlarning aksariyati 500 m dan 1 km gacha boʻlgan fazoviy rezolyutsiyaga ega (1-jadvalga qarang). Shunday qilib, mintaqa yoki mahalliy hududga xos yer qoplamasi turlarining tafsilotlarini aniqlash qiyin boʻladi va bu mamlakatning oʻrmonlarini yanada barqaror boshqarish qobiliyatini xavf ostiga qoʻyishi mumkin.

Masofadan zondlash texnologiyasi. Masofadan zondlash tezlik bilan rivojlanmoqda, ayniqsa, u muhandislik, kompyuter fanlari, geografiya va boshqa turli sohalar o‘rtasidagi texnologik interfeys sifatida faoliyat yuritayotgani sababli [5]. Shuning uchun, bu texnologiya o‘rmon turlari va qiyin yoki murakkab yerlarning xaritalarini tuzish, aniqlash va miqdorini baholash uchun keng qo‘llaniladi, chunki u ishonchli va yangilangan ma’lumotlarni samarali taqdim etadi [11]. Bundan tashqari, so‘nggi yillarda masofadan zondlash integratsiyalashgan tahlil jarayonida qo‘llanilmoqda, bunda optik va radar ma’lumotlari Geografik Axborot Tizimi (GIS) ma’lumotlari, topografik ma’lumotlar va iqlim ma’lumotlari bilan birlashtiriladi. Masofadan zondlash ko‘pincha tasvirni olishdan to‘g‘ri tasniflash va aniqlikni baholashgacha bo‘lgan jarayonni kuzatadi, bu esa 1-rasmda ko‘rsatilgan. Har bir bosqichda sezilarli yutuqlar amalga oshirilmoqda. Quyidagi bo‘limlar ushbu jarayonning har bir bosqichini yanada batafsil tasvirlaydi. Ushbu jarayon maxsus masofadan zondlash dasturiy ta’minotlari yordamida amalga oshiriladi, va ular avval ko‘rib chiqiladi.

Inputs		Suniy yo‘ldosh tasviri va GIS ma’lumotlari (Topografiya, Iqlim ma’lumotlari)			Namuna olish dizayni	
					O‘qitish ma’lumotlari	Manba ma’lumotlari
Masofadan zondlash jarayoni		Radiometrik Geometrik	Fazoviy soha Chastota sohasi Ma’lumotlarni birlashtirish	Spektr To‘qima Topografik	Pikselli asos Obyektli asos	Noaniqlik matritsasi Kappa statistikasi
Jarayon nomi	Tasvirni olish	Tasvirni tayyorlash	Tasvirni yaxshilash	Xususiyatlar ni chiqarish	Tasvirni tasniflash	Aniqlikni baholash

1-rasm. Masofadan zondlash jarayoni

Masofadan zondlash dasturiy ta’minot platformalari

So‘nggi yillarda bir qator tijorat masofaviy zondlash dasturiy ta’minotlari ishlab chiqildi, ular turli kompyuter operatsion tizimlarini ishlatib, katta miqdordagi masofadan zondlash ma’lumotlarini samarali tarzda qayta ishlash imkoniyatiga ega. Bularga quyidagilar kiradi:

1) ENVI – L3Harris Geospatial tomonidan ishlab chiqilgan tijorat masofaviy zondlash dasturiy ta’minoti bo‘lib, u katta multispektral va gipersektral masofaviy zondlash ma’lumotlarini qayta ishlash uchun mo‘ljallangan (https://www.l3harrisgeospatial.com/Software-Technology/ENVI). Ushbu dastur 1974-yildan beri keng qamrovli an'anaviy va an'anaviy bo‘lmagan tasvir tasniflovchilarini taklif etadi va obuna uchun 8370 AQSh dollarini talab qiladi.

2) ERDAS IMAGINE – 1978-yilda Hexagon Geospatial tomonidan ishlab chiqilgan eng qadimgi Geoinformatika dasturlaridan biri (https://www.hexagongeospatial.com/products/powerportfolio/erdas-imagine). Bu dastur tasvir tahlili uchun keng qamrovli va murakkab vositalarni o‘z ichiga oladi va yillik litsenziya uchun 3500 AQSh dollariga teng bo‘ladi.

3) PCI Geomatica – 1982-yilda PCI Geomatics Corporate tomonidan ishlab chiqilgan yetakchi masofaviy zondlash, fotogrammetriya va kartografiya dasturi

(https://www.pcigeomatics.com/index.php). U yuqori darajadagi avtomatlashtirish va moslashtirilgan ish jarayonlarini taklif etadi, obuna uchun 2229 AQSh dollarini talab qiladi.

Masofaviy zondlashning oʻrmonlarni monitoring qilish va boshqarishdagi qoʻllanilishi. Soʻnggi yillardagi kompyuter versiyalari, machine learning va masofaviy zondlash texnologiyalaridagi yutuqlar, oʻrmonlarni global, mintaqaviy va mahalliy miqyosda aniqlash, monitoring qilish, baholash va xaritalashtirish uchun yangi vositalarni taqdim etmoqda. Ushbu qismda masofadan zondlashning barqaror oʻrmonlarni boshqarishdagi qoʻllanilishi uchta kategoriyaga boʻlingan: oʻrmon qoplamasini tasniflash, oʻrmon tuzilishini baholash va oʻrmon oʻzgarishlarini aniqlash.

Oʻrmonlarni tasniflash. Oʻrmon qoplamasi turlari, oʻrmon ekotizimlari va oʻrmon turkumlarini samarali boshqarish uchun fazoviy tarqalishi va tuzilishi haqidagi maʼlumotlar tobora koʻproq talab qilinmoqda. Oʻrmonlarni xaritalash odatda fazoviy, vaqtinchalik yoki taksonomik iyerarxiyalar va geografik hodisalar doirasida amalga oshiriladi [4]. Masofaviy zondlash global miqyosda oʻrmon qoplamasini xaritalash uchun samarali vosita sifatida tan olingan boʻlsa-da, bu oʻrmon qoplamasi sinflaridagi mintaqaviy farqlarni yoʻqotishga olib kelishi mumkin, jumladan, oʻrmonchilik amaliyotlari kabi barqaror oʻrmon tizimlariga oid farqlar [13].

Soʻnggi yillarda masofaviy zondlash texnikalaridagi yangi yutuqlar, jumladan yangi tahlil usullari [14] va sun'iy yoʻldosh maʼlumot manbalari, masalan, Sentinel, radar va LiDAR [15], resurslar cheklangan mamlakatlarda oʻrmon muhitlarini barqaror boshqarishni amalga oshirish va qoʻllab-quvvatlash uchun umidli alternativani taqdim etadi.

Oʻrmon tuzilishi. Oʻrmonning tuzilmaviy xususiyatlari oʻrmon holatini aniqlashda yordam beradigan koʻrsatkichlardir. Ushbu xususiyatlarga oʻrmon tojining yopilish darajasi, koʻkrak balandligidagi diametr, hajm, balandlik, oʻrnashgan joyidagi zichligi, yosh va rivojlanish bosqichi kabi daraxt balandligi va tur tarkibi kiradi [4]. Oʻrmon tuzilishini oʻlchash uchun an'anaviy usullar vaqtni talab qiladigan va qimmatga tushadigan hisoblanadi[16].Sensorlar va platformalar texnologiyasidagi yutuqlar bilan masofaviy zondlash ushbu koʻrsatkichlarni aniqlashda yordam beradi, bu esa ekologik tiklanish va oʻrmonlarni tiklash loyihalarini yaxshilashga yordam beradi.

Oʻrmon oʻzgarishlarini aniqlash. Masofadan zondlash oʻrmonlardagi oʻzgarishlarni hudud boʻylab aniqlash va monitoring qilishda yordam beradi, bu esa barqaror oʻrmon boshqaruvini qoʻllab-quvvatlaydi. Oʻrmon oʻzgarishlari landshaft shakllarida, funktsiyalarda va barcha fazoviy va vaqtinchalik oʻlchovlarda tabiiy va inson omillari hamda ekologik oʻsish tufayli yuz berishi mumkin. Koʻplab misollar masofaviy zondlash tabiiy ofatlar, masalan, toshqinlar, yongʻinlar, shamol, hasharotlar va kasalliklar sabab boʻlgan oʻzgarishlarni aniqlay olishini koʻrsatadi [4].

Oʻrmon yongʻinlari global miqyosda oʻrmon buzilishining asosiy omillaridan biridir va yongʻinlar uzoq muddatli oʻrmon dinamikasi va biologik xilma-xillikka, shuningdek, mahalliy va mintaqaviy miqyosda keng taʼsir koʻrsatadi [17]. Faol yongʻinlarni aniqlash va ularning taʼsiri masofadan zondlashning muhim qoʻllanilishlaridan biri boʻlgan. Yongʻinlar sodir boʻlishini kundalik global kuzatishlar AVHRR, SPOT VEGETATION yoki MODIS sensorlari orqali amalga oshiriladi [4].

Oʻrmon yongʻinidan soʻng, oʻrmon buzilishining asosiy sabablari hasharotlarning ommaviy chiqishlari va shamoldir [17], bu odatda maydon faoliyatlari orqali oʻrganiladi, bunda masofadan zondlashning taʼsiri kamdir. Bir nechta tadqiqotlar sogʻlom va stressga uchragan daraxtlarni oʻrgangan, boshqalari esa erta aniqlash, barg toʻkilishi va oʻrmon shikastlanishini baholashga eʼtibor qaratgan [18]. Biroq, masofadan zondlash yordamida oʻrmon salomatligini doimiy kuzatib borish uchun aniq ehtiyoj mavjud.

Kelajakdagi ilmiy tadqiqotlar. Masofadan zondlash jarayoni ushbu maqolada koʻrib chiqilgan koʻplab bosqichlardan iborat. Ushbu bosqichlarni yaxshilash imkoniyatlarini rivojlantirish uchun koʻplab tadqiqot imkoniyatlari mavjud. Ushbu muhokama qismida ayniqsa rivojlanayotgan mamlakatlarning ehtiyojlariga alohida eʼtibor qaratgan holda, bu tadqiqot imkoniyatlarining baʼzilari taʼkidlanadi.

Soʻnggi yillarda aniqlikni baholash texnikalari boʻyicha muhim tadqiqotlar olib borildi, chunki ular amaliy va nazariy jihatlarda katta ahamiyatga ega [19]. Garchi kappa masofadan zondlash tadqiqotlarida keng qoʻllanilgan boʻlsa-da, bu koʻp tanqid qilingan, chunki tasodifiy kelishuv darajasi ortiqcha baholanishi mumkin [20]. Foody [19] kappa koeffitsientining tasodifiy kelishuv ekanligini va bu aniqlik koʻrsatkichi emasligini taʼkidladi, shuning uchun aniqlikni baholash oxir-oqibat adashgan matritsa va har bir sinf boʻyicha aniqlik bilan amalga oshirilishi kerak, deb hisoblaydi. Wang va Weng [20] shuningdek, kappa tahlili faqat matritsadagi barcha xatolar bir xil ahamiyatga ega deb hisoblanganda mos kelishini taʼkidlaydilar. Bunday holatda oʻrmon xaritalash uchun yangi aniqlikni baholashni ishlab chiqish yoki kappa statistikalarining amaldagi samaradorligini tekshirish uchun koʻproq tadqiqot imkoniyatlari mavjud.

Doimiy bulut qoplamasi tropik oʻrmon tadqiqotchilari uchun koʻpincha muammo tugʻdiradi. Soʻnggi yillarda, Sentinel 1 radar maʼlumotlari tropik hududlarda bulut qoplamasi cheklovlarini yengishga yordam bermoqda [15], lekin yuqori aniqlik uchun maʼlumotlarni birlashtirish afzalroqdir, chunki bu turli xil maʼlumot manbalarini vaqt va makon boʻyicha farq qiluvchi chegaralar bilan birlashtiradi. Garchi tropik oʻrmon tadqiqotlari fazoviy radar va optik maʼlumotlarni birlashtirishga qaratilgan boʻlsa-da, vaqt boʻyicha agregatsiyani oʻrganish uchun koʻproq tadqiqotlar zarur [12]. Shuningdek, Janubiy Osiyo hududlari, daraxt kesilishi (oʻrmonlarning yoʻqolishi) va degradatsiya uchun juda dinamik hududlar boʻlib, ular Yevropa, Xitoy va Shimoliy Amerika qitasida oʻrmonlarni barqaror boshqarish uchun vaqt boʻyicha oʻzgarishlarni aniqlashga qaratilgan tadqiqotlar bilan solishtirganda yetarlicha oʻrganilmagan [21].

Machine learning algoritmlaridagi rivojlanishlar va ochiq maʼlumotlarga kirish imkoniyatlari bulutli platformalarda katta hajmdagi hisoblashlarni amalga oshirishni osonlashtirdi, bu esa global miqyosda vaqt boʻyicha tahlilga olib keldi. Bunga qarshi, kichik agroforestriya sinflari, mamlakatlar va madaniyatlar uchun muhim boʻlib, koʻpincha global maʼlumotlar toʻplamlaridan chetda qoladi. Ushbu taʼsirni minimallashtirish uchun rivojlanayotgan mamlakatlarda barqaror oʻrmon amaliyotlari uchun muhim boʻlgan xususiyatlarni, masalan, uy bogʻlarini aniqlashga qaratilgan koʻproq masofadan zondlash tadqiqotlari oʻtkazilishi kerak [22].

Agar LiDAR mahsulotlari iqtisodiy jihatdan samarali boʻlmasa, katta hududda oʻrmon oʻzgaruvchilarini baholash uchun ochiq manbali maʼlumotlarning imkoniyatlarini oʻrganish zarur. Bunday holatda, yaqinda ishga tushirilgan missiyalar, masalan, GEDI [23], oʻrmon balandliklarini baholashda yordam beradi, va tez orada ishga tushiriladigan missiyalar, masalan, BIOMASS missiyasi, p-banda sintetik aperturali radarni olib yuradi, bu oʻrmon uglerodini hisoblashda katta potensialga ega [24]. Bundan tashqari, Mission Algorithm and Analysis (MAAP) — NASA va ESA tomonidan oʻrmon biomassa mahsulotlarini yaratish uchun ishlab chiqilgan bulutga asoslangan platforma boʻlib, 2021-yildan toʻliq ishga tushgan. MAAP asosan Biomass NISAR (NASA-ISRO SAR Missiyasi) va GEDI kabi kosmosdan olingan maʼlumotlar toʻplamlaridan ekotizim tuzilmalarini xaritalash uchun maxsus ishlab chiqilgan vositalar va algoritmlardan iborat [25]. Ushbu imkoniyatlar rivojlanayotgan mamlakatlarga oʻrmon degradatsiyasini oʻrmon yoʻqolishiga aylanishidan oldin kuzatish va boshqarish imkonini beradi, shuningdek, SDG 15 (Barqaror rivojlanish maqsadi 15) uchun yoʻl ochadi.

Xulosa. Barqaror Rivojlanish Maqsadlari (SDG) 2030-yilga qadar erishilishi kerak boʻlgan 17 ta keng qamrovli maqsadlari bilan global barqarorlikka eʼtibor qaratish uchun belgilangan. Oʻrmonlarni muhofaza qilish va boshqarishga SDG-ning 15-maqsadi doirasida alohida eʼtibor qaratilgan, chunki bu insonlarning turmush tarziga va kambagʻallikni qisqartirishga katta ahamiyatga ega. Shuning uchun, oʻrmon strukturasining aniqligi hamda fazoviy va vaqt boʻyicha oʻzgarishlarni aniqlash barqaror oʻrmon boshqaruvi uchun juda muhimdir. Bunday holatda, masofadan zondlash oʻrmon degradatsiyasini, oʻrmon yoʻqolishini kuzatish va oʻrmon oʻzgaruvchilarini oʻlchash uchun ishonchli usul hisoblanadi. Soʻnggi oʻn yilliklarda, masofadan zondlash, machine learning va GIS sohalaridagi yutuqlar oʻrmon tadqiqotlarini oʻtkazishning yangi usullarini yaratdi. Masofadan zondlashdagi eng katta yutuq ochiq manbali maʼlumotlarning mavjud boʻlishi bilan yuz berdi, undan keyin ochiq manbali yoki bepul dasturlar va bulutga asoslangan platformalarning takomillashuvi sodir boʻldi. Ushbu omillar rivojlanayotgan mamlakatlarga oʻrmonlarni samarali va tezkor tarzda tadqiq qilish va kuzatish imkonini beradi.

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ТУПРОҚ УНУМДОРЛИГИНИ ОШИРИШНИНГ ТАЖРИБАЛАР АСОСИДА ЯРАТИЛГАН ЯНГИ ИННОВАТSIОН УСУЛИ.

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UDC: 631.43: 528.8

STUDY OF MONITORING SOIL EROSION IN AGRICULTURAL LANDS USING GIS TECHNOLOGIES (IN CASE KASHKADARYA REGION).

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***Annotatsiya**: Ushbu tadqiqot qishloq xo'jaligida foydalanish uchun ko'proq mos keladigan unumdor tuproqlarning yo'qolishida tuproqning muhrlanishi va uning oqibatlarini tahlil qiladi. Bundan tashqari, tuproqning muhrlanishi suv toshqini xavfini oshiradi. Asosiy maqsad Yakkabog' daryosi havzasida (Qashqadaryo, O'zbekiston) 2010-2020 yillar oralig'ida tuproq yo'qotilishini aniqlashdan iborat. Sun'iy yo'ldoshdan olingan suratlarni raqamli qayta ishlash (Normallashtirilgan o'simliklar farqi indeksi (NDVI), asosiy komponentlar va konvolyutsiya filtrlari)ning uyg'unligi raqamli erlar modelini va dengizdagi xavfli hududlarni tez aniqlash imkonini beradi. Tasvirlarning nazorat ostidagi tasnifi Yakkabog' daryosi havzasida muhrlanish yo'li bilan haqiqiy tuproq yo'qotilishini, yo'qolgan turlari va agrologik sinflarini aniqlash uchun foydalanilgan. Tuproqning yo'qolishi ko'proq darajada o'tkazuvchanligi yuqori tuproqlarda (qumlarda) va eng unumdor tuproqlarda sodir bo'ladi. Asosiy muhrlangan tuproq birlashmalari luvisollar (alfisollar), regosollar (entizollar) va kambisollar (inceptisollar) dir.*

***Kalit so'zlar:** tuproq eroziyasi, ta'sir, masofadan zondlash, Qashqadaryo*

***Abstract:** This study analyzes soil sealing and its repercussions in the loss of fertile soils, which are more appropriate for agriculture use. Also, soil sealing increases flood risk. The main objective is to estimate soil loss by sealing in the Yakkabog River Basin (Kashkadarya, Uzbekistan) between 2010 and 2020. The combination of digital processing (Normalized Difference Vegetation Index (NDVI), principal components and convolution filters) of satellite imagery with the digital terrain model helps to detect risk areas and allows quick updating of sealed soil mapping. The supervised classifications of the images were used to estimate the actual soil loss by sealing in the Yakkabog River Basin and the types and agrologic classes that have been lost. Soil loss occurs to a greater extent in highly permeable soils (sands) and in the most fertile soils. The main sealed soil associations are luvisols (alfisols), regosols (entisols) and cambisols (inceptisols).*

***Keywords:** soil erosion, impact, remote sensing, Kashkadarya*

***Аннотатсия**: В этом исследовании анализируется запечатывание почвы и его последствия в потере плодородных почв, которые более*

подходят для сельскохозяйственного использования. Кроме того, запечатывание почвы увеличивает риск наводнений. Основная цель - оценить потерю почвы из-за запечатывания в бассейне реки Яккабог (Кашкадарья, Узбекистан) в период с 2010 по 2020 год. Сочетание цифровой обработки (нормализованный индекс разности растительности (NDVI), главные компоненты и сверточные фильтры) спутниковых снимков с цифровой моделью рельефа помогает обнаружить зоны риска и позволяет быстро обновлять картографирование запечатанной почвы. Контролируемые классификаtsii изображений использовались для оценки фактической потери почвы из-за запечатывания в бассейне реки Яккабог, а также типов и агроклассов, которые были потеряны. Потеря почвы происходит в большей степени в высокопроницаемых почвах (песках) и в самых плодородных почвах. Основные ассоциаtsii запечатанных почв — лювисоли (альфисоли), регосоли (энтисоли) и камбисоли (инцептисоли).
Ключевые слова: *эрозия почвы, воздействие, дистанционное зондирование, Кашкадарья*

Introduction: Many studies analyze urban growth and its implications for planning and land use. Urban development often prioritizes viability and economic profitability over environmental criteria. In periods of a significant decline in agricultural, livestock farming and forestry activities, little attention has been paid by urban planning to soil quality, and considerable sealing of high or medium quality soils has taken place. This is a serious environmental problem that has been analyzed by various authors on different scales. Estimated soil loss from sealing was 9% in Europe from the mid-1980s to the late 1990s [2], 7% in the city of Nanjing in China 1984–2003 [3], and 4.5% in the US during the 1990s [4]. Soil erosion sealing is a direct result of urban growth and is seldom included in environmental impact assessments. Some of the changes that it triggers in ecosystems have been minimized, including variations in the water balance [5]. Soil erosion alters the water cycle and increases flood risk due to ground impermeability. This impermeability is irreversible when sealing is due to artificial materials, but where there is only soil compaction with no artificial cover, it may be reversible. For this reason it is essential to maintain open, unsealed zones in urban areas or, where sealing is unavoidable, to use "semi-sealing" which leaves some infiltration capacity in green spaces, recreation areas, etc. The most serious impact occurs when the underlying subsoils are highly permeable [6] and the greater surface run-off increases the quantity of sediments and contaminants. It would therefore be preferable to build on low-infiltration-capacity soils (clays) and minimize the sealing of the most permeable soils (sands) to facilitate infiltration. Urban planning should take hydrological properties or soil permeability into account to a greater extent [7,8].

This study analyzes soil sealing and its repercussion on the loss of fertile soils, which are most appropriate for agricultural use. Soil erosion also has a negative impact in terms of increased flood risk. A methodology is proposed to monitor and evaluate soil sealing using satellite images available worldwide [9]. These land-monitoring techniques should be incorporated into thematic cartography for use by local authorities. In methodological terms, this article includes a digital analysis (radiometric, spectral and spatial enhancement) of Spot images, compared with only the visual interpretation of satellite images to detect and measure soil sealing in Spain. This study also evaluates soil loss, taking into account the soil type and its agrological capacity.

For this case study, a highly dynamic area of urban development in central Spain was selected, where soil sealing has increased significantly over the last 30 ears. Remote sensing facilitated the location of the sealed areas and the continuous monitoring of the changes that have occurred, although it is often difficult to define these areas exactly unless high spatial resolution images are available. This problem was solved using information obtained from large-scale aerial photos and in situ verification. However, the lower temporal resolution of photogrammetric flights (at five- or ten-year intervals in Spain) versus the continuous updating of satellite images led to the conclusion that detecting soil sealing by processing satellite images is a better approach. Mapping soil erosion using images is not always straightforward due to the heterogeneity of built-up surfaces, which are often mixed with natural areas, and to the wide range of construction types: housing, industrial buildings, communication routes, recreation areas, etc. Other authors have attempted to solve this problem proposing different analysis methods, with significantly different results depending on the required precision and the case study environment. Ridd considers that soil texture is an important factor to take into account in a model using remote sensing and considers the V-I-S (vegetation-impervious-soil) model useful for urban studies [10].

Nizeyimana uses the Soil Rating for Plant Growth SRPG model based on the Digital General Soil Map of the United States (STATSGO) soil and landscape attributes and climate [11]. Wu, 2004, developed a normalized spectral mixture analysis SMA method to quantify urban composition within the framework of the V-I-S model [12]. Valera et al. used photointerpretation of aerial photographs and Geographical Information System GIS-based map analysis to establish changes in land use from 1956–2006 in a Mediterranean area [13]. Kampourakiet al. used a maximum likelihood classification of Normalized Difference Vegetation Index (NDVI) images derived from Quick Bird data and aerial photographs [14]. For this study, the NDVI was selected and supervised classification was carried out using the parametric rule of minimum distance as this obtained the best results in a semi-arid area with sand- and clay-rich detritic sediments [15].

The main objectives of this paper are to:

- Assess the surface areas that still allow some soils to be used for agriculture.
- Calculate the percentage of soil sealed over the last 50 ears from a multi-temporal analysis of satellite images and aerial photographs.
- Determine what type of land the sealing process affects.
- Analyze the surface horizons of the most fertile soils to discover the physical and chemical properties lost through sealing.

- Perform a semi-automatic classification of sealed surfaces from the image obtained with the most suitable spectrum improvement.
- Compare results of the classifications with the actual terrain and available digital cartography.

Study Area. Here sealing is analyzed for soils in the Yakkabog River Basin near Kashkadarya, Uzbekistan ($37^{0}58/-39^{0}32/$, $64^{0}23/-67^{0}42/$) (Figure 1), with an area of 3220 ha. This area of highly permeable soils has undergone a significant increase in sealing in recent ears. The supply to the Yakkabog River is nivopluvial, with a maximum daily flow rate of 28.1 m3/s and a maximum instantaneous flow rate of 18.3 m3/s. However, its mean flow is only 7.3 m3/s, implying significant periods of low flow.

Although the flood risk in the Yakkabog Basin is relatively low, the presence of buildings in some parts of the flood plain is a matter of concern, as historic water levels have risen more than 1 m. In addition, a reservoir at the basin head would represent an increased risk in a possible dam failure scenario. The deforestation of some areas, the extraction of aggregates and, in extreme cases, massive water discharges from a reservoir in the upper reach of the river also increase the flood risk. In 1996–1997, floods did affect the area, caused by problems that may recur in very wet hydrological ears or if water is released from the reservoir.

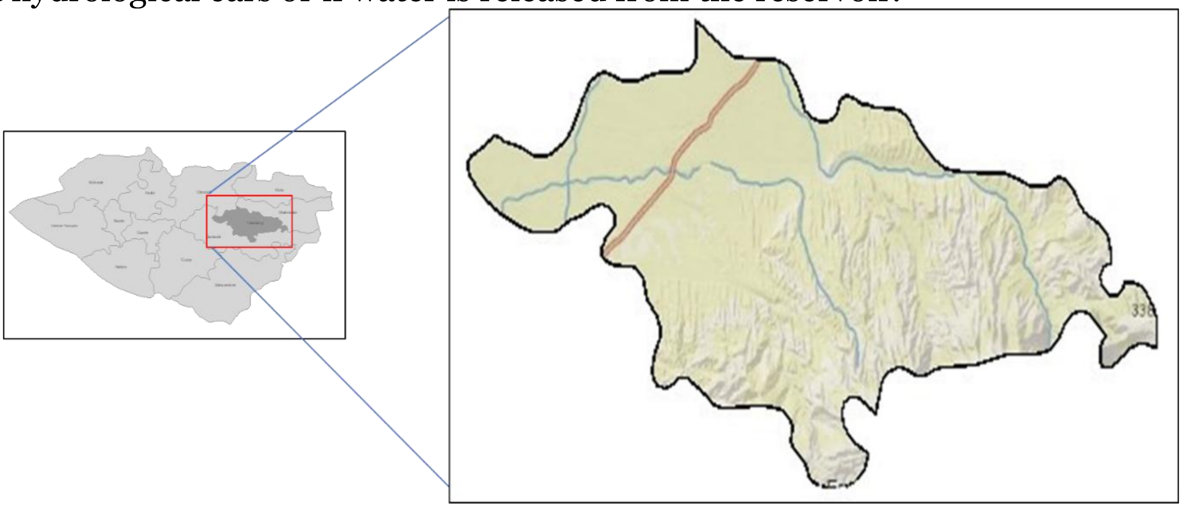

Figure 1. Study area: Yakkabog River Basin, Yakkabog, Kashkadarya

The basin lithology is highly homogeneous and is formed by two main groups. The headwaters in the Sierra flow through Late Hercynian granites and glandular gneiss. The rest of the basin is formed by arkosic sands with gravel and clay layers prone to alteration. There is also a clear decrease in sand grain sizes and more clays towards the lower reaches of the river, increasing the risk of erosion. The river channel is confined within a gently sloping valley, flanked by remnants of multiple terraces; the highest of these are predominantly gravels, gradually becoming increasingly sandy downstream. In the lower reaches, the valley widens and becomes flatter, blurring the outline of the terraces. Here the slope contributions and remobilization of material by lateral fans become especially significant and are fundamental in the channel supply during flooding. The flood plain is not well defined and has a maximum width of 1 km in the lower reach [16].

Two features condition the flood risk: In this river, the morphological and sediment logical limits between the high water channel and the flood plain are not clearly defined and the sandy banks are very unstable, facilitating remobilization. Another significant effect is the subsurface bank erosion process resulting from the sandy composition, the intercalations of clay materials, and the elimination of protective vegetation. The result is that gullies of up to tens of meters long have formed on the banks, with various housing developments built on them.

Material and Methods. In this paper, the two thematic classifications to calculate the loss of soil due to sealing in the last 50 ears are compared. The surface affected by soil sealing on the dates analyzed was obtained by photointerpretation and digital image processing. The urban core and road infrastructures on different dates are digitalized and the surface of discontinuous sealing (between 5%–50%) and continuous sealing (>50%) is calculated. Further, in the satellite images the urban surfaces of other non-sealed soil cover are separated (bare soil, wasteland and vegetation). These classes cannot be manually separated in the aerial photography due to the limitations of scale and the lack of infrared channels that would add spectral information about the vegetation.

Aerial photographs were used for the period 1961–1967 [17]. Panchromatic, multispectral Spot-5 satellite images from 27 August and 28 November 2011 were obtained from the National Geographical Institute.

Soil loss from sealing in the 1960 s was measured from the visual interpretation and manual digitization of aerial photographs in the Yakkabog Basin. The image obtained is a mosaic of the existing photos from 1961–1967. Although the dates do not coincide throughout the basin, there is no other existing material to build the image of this period.

The Yakkabog Basin, where the soil sealing was analyzed, was overlaid on the Digital Terrain Model (DTM) and all the images were geo-referenced to Universal Transverse Mercator UTM coordinates (grid zone 30T) and Datum ETRS89. The DTM was obtained from the Shuttle Radar Topography Mission, Global Land Cover Facility Internet server [18], with a Capture Resolution of 3 arc second (90 m of spatial resolution) [18,19].

The Spot images were processed with Erdas Imagine-2011 software, carrying out different spectral enhancements (NDVI, principal components and band combinations), radiometric enhancement (histogram equalization) and spatial enhancements (convolution filter 3 × 3 and the resolution merge of panchromatic and multispectral images). These techniques attempt to highlight different land uses in the images and are based on the following parameters:

- NDVI (Normalized Difference Vegetation Index): this index differentiates the high spectral response of vegetation in the near-infrared band from the low response in the red. Sealed soils have negative values. The mathematical algorithm is:

$$\mathrm{NDVI} = \frac{(NIR - Red)}{(NIR + Red)}\,; \qquad (1)$$

- The principal components factor analysis is based on summarizing a large number of variables into a smaller group, with hardly any loss of information, taking the variance matrix into account. In remote sensing, the variables will be the different sensor bands and this analysis is used to obtain a new image, in which the first components will represent almost the entire variability. The urban land always has a regular geometric or spatial pattern.

-Equalization enhances the contrast in the image. In this operation the grayscale color is assigned by the digital pixel value and also by the frequency distribution of the orthogonal digital numbers, so that the visual number assigned to each digital number is proportional to its value and frequency. Although histogram equalization is a routine method, it has been selected in this case because it clearly shows the different soil covers, highlighting anthropic elements (buildings and infrastructure).
-The convolution filter enables improved separation of the linear elements, as these are poorly represented in the original images. This filter sums the values of a pixel and its 3 × 3 neighborhood to obtain a better spatial representation of cultivated cropland, riverbank vegetation and garden surfaces.

-Resolution merges between panchromatic and multispectral channels: To improve the detail in the final image the multispectral image has been merged with the panchromatic satellite image.

Previous work has shown that part of the surface digitized as sealed soils corresponds to an open urban type, which leaves large non-built (i.e., non-sealed) areas [17,18]. To assess the real surface with irreversible loss of soil infiltration capacity, supervised classifications by the parametric rule of minimum distance were carried out by setting up five categories of soil occupation, three of which are related to sealing and two are related to undeveloped land: bare soil (<5% sealed soil), discontinuous sealing (5%–50% sealed soil), continuous sealing (>50% sealed soil), vegetation, wasteland, in the photos and images dating from 2001–2009 and 2011, respectively.

A confusion matrix was used to check the accuracy of the classifications, contrasting the results with the existing maps on both dates [17] and with the ground truth data verified in September 2011. Although the most recent orthophotos of Yakkabog (Yakkabog Community, 2010; Scale 1:5000) enable high precision visual interpretation confirming the field data, 50 random sampling points were chosen and their accuracy was checked. These samples were taken only on surfaces classified as sealed soil (continuous and discontinuous) with a random distribution of points.

Calculation of the sealed soil surface also included the digital processing of road infrastructures, as the vectorial layers with this information tend to refer to lines. It was considered that the soil used for linear infrastructure should not be ignored in the soil sealing analysis.

Results and discussion. One of the main factors determining soil fertility is its water-physical properties. Here, mainly soil density, volumetric and specific mass, total porosity, water permeability, and moisture capacity are of great agronomic importance [7]. The water-physical properties of the soil vary depending on the type of soil, mechanical composition, structure, amount of organic and mineral substances, structure, culture, and level of tillage [12]. Pasture soils are soils with naturally favorable water-physical properties. In this case, this type of soil determines the air, heat, nutrients, water regime and the activity of microorganisms, as well as the growth and development of plants. This is considered as one of the main factors determining the methods and irrigation regime of vineyards.

The soil of the experimental field is light gray, grazing, medium mechanical sandy soil, with a small amount of humus, and the absorption of mineral colloids is considerably fast [9]. In the upper layers, their variation varies from 8 to 9 mg.equiv. (per 100 g of soil). The primary data on the water-physical properties of the experimental field soil density, solid phase density, soil porosity, maximum hydroscopic, and moisture reserve are given in Table 2.

Table 2. Water-physical properties of experimental field soils.

Soil layer, cm	Density, ton/m³	Solid phase density, ton/m³	Soil porosity, %	Maximum hydroscopicity soil mass, %
0-20	1.33	2.61	52.9	5.2
20-40	1.39	2.72	50.7	5.3
40-60	1.45	2.73	48.8	5.4
60-80	1.44	2.68	48.1	5.2
80-100	1.35	2.66	47.7	5.3
0-60	1.37	2.68	50.7	5.3
0-80	1.45	2.68	50.0	5.2
0-100	1.39	2.68	49.6	5.4

To calculate the amount of water used in drip irrigation networks for irrigation of orchards and the cost of irrigation to determine the net income from the garden at the end of the ear is important. In the experimental field conducted in the conditions of the soils of this study area, 0.3-0.5 and 0.7 m layers of vineyard soil were irrigated by drip irrigation system with moisture supply. In this case, the control option provided 0.7 m layer of soil with moisture and irrigated in the order of 70-75-65% relative to LFMC. Fertilization norms used on the farm to feed the orchards and vineyards were 120 kg of nitrogen, 90 kg of phosphorus and 30 kg of potassium fertilizers per hectare.

Depending on the level of soil moisture, the capillary pores up to the lower layers of the soil to be high or low depend on the soil layer to be filled with water, and to be low in winter and high in autumn in sudden changes in air temperature. LFMC of the soil is understood to be the ability to retain water in layers that have been absorbed into the soil to varying degrees [8]. The higher the moisture capacity of the soil at the site of the experiment, the more moisture is provided in the soil for the plant.

Conclusions: Remote sensing for the assessment and monitoring of soil sealing provides up-to-date and highly reliable information. This technique allows one to evaluate the potential impact of soil sealing in agricultural areas. Mapping and quantifying soil sealing using high spatial resolution satellite images gives very good results, as this study shows. These images enable the correct identification of different urban typologies, although delimiting soil sealing in open urban development with wooded areas is problematic. The digital processing of linear communication routes using polygons (not lines) allows for a more accurate calculation of soil loss from sealing. In the immediate surroundings of large cities these infrastructures can be significant. These land-monitoring techniques should be incorporated into the tools used by the relevant local authorities.

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SCIENTIFIC APPROACHES TO THE COLLECTION AND INTERPRETATION OF DATA ON THE ENVIRONMENT

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Annotatsiya. *Ushbu maqola atrof-muhit ma'lumotlarini to'plash va tahlil qilishning ilmiy usullarini tahlil qilindi. Tadqiqotda turli manbalardan olingan ma'lumotlarni taqqoslashdagi qiyinchiliklar hamda ma'lumotlarning ishonchliligini tekshirish uchun standartlashtirilgan metodikalarga ehtiyoj borligi ta'kidlandi. Atrof-muhit monitoringida lidar texnologiyasi, gamma-spektrometriya va optik masofaviy zondlashning ahamiyati muhokama qilindi. Shuningdek, ekologik atlaslarni yaratish jarayonining asosiy bosqichlari, jumladan, qo'llash sohasi, tizimni loyihalash va ma'lumotlarni yig'ish muhimligi yoritib berildi. Tadqiqot natijalari atrof-muhit ma'lumotlarining aniqligi va integratsiyasini oshirish orqali samarali qaror qabul qilishga hissa qo'shadi.*

Kalit so'zlar: *GAT, lidar texnologiyasi, masofadan zondlash, ekologik atlas.*